# HAWAII AGRICULTURAL WATER USE AND DEVELOPMENT PLAN

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Section 2

| | |
|---|---|
| ALISH | Agricultural Lands of Importance to the State of Hawaii |
| Emerge | The Emerge Digital Sensor System (Advanced Airborne Digital Camera) |
| IKONOS | The IKONOS Fine Resolution Satellite Sensor |
| ETM+ | Enhanced Thematic Mapper Plus |
| GIS | Geographic Information Systems |
| LCC | Land Capability Classes |
| LULC | Land Use/Land Cover |
| LCD | Least-Cost Distance |
| STATSGO | U.S. General Soil Map |

Section 3

| | |
|---|---|
| AWD | Available Water Depletion |
| CN | Curve Number |
| ET | EvapoTranspiration |
| EVI | Type I Extreme Value Distribution |
| HARC | Hawaii Agricultural Research Center |
| IRR | Irrigation Requirements |
| LAI | Leaf Area Indices |
| NCDC | National Climate Data Center |
| PE | Pan Evaporation |
| SCS | Soil Conservation Service |
| USDA | United States Department of Agriculture |

Section 4

| | |
|---|---|
| O&M | Operations and Management |

Section 5

| | |
|---|---|
| DBEDT | (Hawaii) Department of Business, Economic Development & Tourism |
| GDP | Gross Domestic Product |
| HASS | Hawaii Agricultural Statistics Service |
| HECO | Hawaiian Electric Company |

Section 6

| | |
|---|---|
| MGD | Millions of gallons per day |

# PREFACE

This report covers the latest (2007) phase of the Agricultural Water Use and Development Plan (AWUDP) of the Department of Agriculture, State of Hawaii. The first (2004) phase documented thirteen active irrigation systems. That study focused on transforming former plantation systems to diversified agriculture use, as well as maintaining systems already devoted to diversified agriculture use by (1) inventory and plan for the rehabilitation of the irrigation systems, (2) identification of irrigable lands for diversified agriculture, and (3) forecasts of acreage and water needs for diversified agriculture for each irrigation system over a 20-year planning period. The goals of the plan were to replace much of Hawaii's imported produce with locally grown produce, pursue niche and off-season markets of fruits and vegetables for export, grow new or Asian-based specialty crops for export, and meet increased demand from the tourism and cruise ship industries for fresh fruits and vegetables. The plan necessitated further work including field verification of farms, service areas, and inclusion of systems not covered in the 2004 report.

The purpose of the AWUDP 2007 research was to estimate current and future agricultural irrigation water demands for irrigation systems across the state of Hawaii. The project contract included development of concepts, methodologies and procedures to produce the following: 1) crop irrigation water duties at 10 irrigation systems, 2) state agricultural industry water projections under different scenarios, 3) water demand projections for 10 irrigation systems, 4) GIS maps and spatial analysis of the service and surrounding areas for 10 irrigation systems, 5) GIS maps for 11 previously unstudied irrigated areas identified in AWUDP 2004.

The research was conducted by the University of Hawaii's College of Tropical Agriculture and Human Resources. The Principal Investigators were Dr. Ali Fares (Associate Professor, Watershed Hydrology and Tropical Soils), Dr. Carol Ferguson (Associate Professor, Natural Resource and Environmental Policy) and Dr. Tomoaki Miura (Assistant Professor, Natural Resource Inventory and Remote Sensing). Cooperating faculty included Dr. Richard Bowen (Specialist, Natural Resource Policy) and Dr. Catherine Chan-Halbrendt (Professor, Agricultural Economic Development and Environmental Management). We acknowledge the contributions of other project personnel including Dr. Theodore Radovich, Dr. Ahmet Dogan, Dr. Farhat Abbas, Rick Chesler, and the graduate students who assisted with data collection and analysis.

The project acknowledges the staff from the sponsoring agencies, the Hawaii Department of Agriculture and the state Commission on Water Resource Management, who provided direction, data, and feedback on the study. The authors would also like to thank water managers and farmers at the irrigation systems visited, experts who served on Delphi survey panels, and respondents to a bioenergy survey for valuable information and insights on Hawaii irrigated agriculture.

# EXECUTIVE SUMMARY

## Background on Study

This is the final report of a study conducted by the College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa (UHM). It was completed under a contract with the Hawaii Department of Agriculture and the state Commission on Water Resource Management. The study is one in a series from two different governmental directives, the federal Hawaii Water Resources Act (HWRA) of 2000 and the Hawaii state Agricultural Water Use and Development Plan (AWUDP). The plan is not intended to be adopted by the counties as their agricultural plan.

In the Hawaii Water Resources Act, the U.S. Congress authorized a special study with four specific tasks:

(a) survey of irrigation and other agricultural water delivery systems
(b) estimates of repair and rehabilitation costs for such systems
(c) evaluation of options and alternatives for improving system water use and conservation that would contribute to agricultural diversification, economic development and environmental quality, and
(d) identification and investigation of opportunities for recycling, reclamation, and reuse of water and wastewater for agricultural and nonagricultural purposes.

The study was to be conducted jointly by the U.S. Department of Interior through the Bureau of Reclamation and the State of Hawaii. Partial federal funding was appropriated, which was matched by state funds. The U.S. Bureau of Reclamation has provided oversight for the study including work by outside contractors.

The Hawaii Water Code (Hawaii Revised Statutes Chapter 174C) requires the Commission on Water Resource Management (CWRM) to comprehensively plan for management and regulation of the state's water resources. The CWRM adopted the first Hawaii Water Plan in 1990. Ten years later, the CWRM adopted a framework to update the plan (CWRM, 2000). The state Department of Agriculture is responsible for updating the Agricultural Water Use and Development Plan (1998 Session Laws of Hawaii, Act 101). These water studies have been divided into phases to accommodate the diverse scope and intermittent availability of funds.

The first study (Water Resource Associates, 2004) focused on irrigation infrastructure available for agricultural use (HWRA tasks a and b). Selected irrigation systems were surveyed on current conditions, with an assessment of infrastructure needs. The systems covered in the 2004 study are listed in Table ES1. The 2004 study began developing a GIS (Geographic Information System) database for Hawaii irrigation systems, including main infrastructure facilities and service area in the selected systems. Due to time and data limitations, system rehabilitation costs were estimated for only a subset of the surveyed systems. The results and GIS data from the 2004 study were made available for the follow-up study covered by this report.

## Study Scope and Methodology

This study built on the 2004 work and addresses other topics mandated by HWRA. The four main components were:

- additional GIS analyses for 10 previously "studied" irrigation systems including potential for wastewater reuse, plus initial database development for another 11 "unstudied" irrigated areas within 7 systems not covered in the 2004 inventory (HWRA tasks a and d)
- development of a farm-level water use model and estimation of irrigation water requirements for selected crops categories at the 10 studied systems (HWRA task c)
- data collection and assessment of long-run agricultural potential at the 10 studied systems (HWRA tasks a and c)
- projections of state agricultural irrigation water demand to the year 2030 by island and for the 10 studied systems, with assessment and preliminary projections for potential bioenergy crops (HWRA task c).

The available funds limited the number of irrigation systems that could be incorporated into this study. The specific systems (Table ES1) were selected by the sponsoring agencies in consultation with the contracted UHM research group. Figure ES1 shows the location of all systems covered in the 2004 and 2007 studies. The remainder of this subsection summarizes the methods and outputs from the four main study components. Important findings are discussed in the subsections that follow.

Table ES1: Master List of Irrigation Systems Covered in the 2004 and 2007 Updates

| No. | Irrigation Systems (location) | 2004* | 2007* |
|---|---|---|---|
| 1 | Waimea IS | Y | Y |
| 2 | East Kauai IS (Kapaa-Kalepa) | Y | Y |
| 3 | Molokai IS | Y | Y |
| 4 | Waiahole Ditch IS | Y | Y |
| 5 | Lower Hamakua Ditch IS | Y | Y |
| 6 | Upcounty Maui IS (Olinda-Kula) | Y | Y |
| 7 | Waimanalo IS | Y | Y |
| 8 | Kekaha IS | Y | Y |
| 9 | Kokee Ditch IS | Y | N |
| 10 | Maui Land & Pineapple/Pioneer Mill IS | Y | N |
| 11 | West Maui IS (Wailuku) | G | Y |
| 12 | Kauai Coffee IS | G | Y |
| 13 | Kilauea IS | N | G |
| 14 | East Maui IS | G | N |
| 15 | Anahola Ditch IS | N | G |
| 16 | Olokele Ditch IS | N | G |
| 17 | Waialua IA | N | G |
| 18 | Kawailoa IA | N | G |
| 19 | Kau Agribusiness IS | N | G |
| 20 | Lihue-Koloa IA | N | G |
| 21 | North Kohala IS | N | G |

Abbreviations: IS=irrigation system, IA=irrigated area
*Studied systems: Y=yes, N=no, G=GIS data only.

The ***GIS analysis*** for the 10 ***studied systems*** added new data layers to the 2004 database. System service areas were overlaid with secondary data on ALISH (Agricultural Lands of Importance to the State of Hawaii) and soil types represented by the USDA's Land Capability Classification (LCC). "Current" land uses and types of crops grown were derived from airborne and satellite imagery acquired in or after 2000, ground-truthed during system visits and interviews conducted in 2006. The augmented GIS database was used to derive varied information on land resources including irrigable area, cultivated area, and rough estimates (estimated 60-80% accuracy) of crop acreages. The project produced three GIS maps for each studied system showing ALISH prime lands, LCC classes, and land uses. Another 11 irrigated areas of interest within previously ***unstudied systems*** were identified in Chapter 3 of the 2004 report. Information on irrigation infrastructure and basic system attributes was collected and added to the GIS database. Potential service area was derived within the GIS from elevation and land use information. GIS maps were produced for the unstudied systems showing location of irrigation facilities and extent of potential service areas. For ***wastewater reuse***, the locations of government-owned wastewater recycling facilities were entered in a GIS database. Zones of potential irrigation reuse were computed as linear horizontal distances from a wastewater source. Six GIS maps of reuse zones were created for regions of Oahu, Maui, Kauai and Molokai.

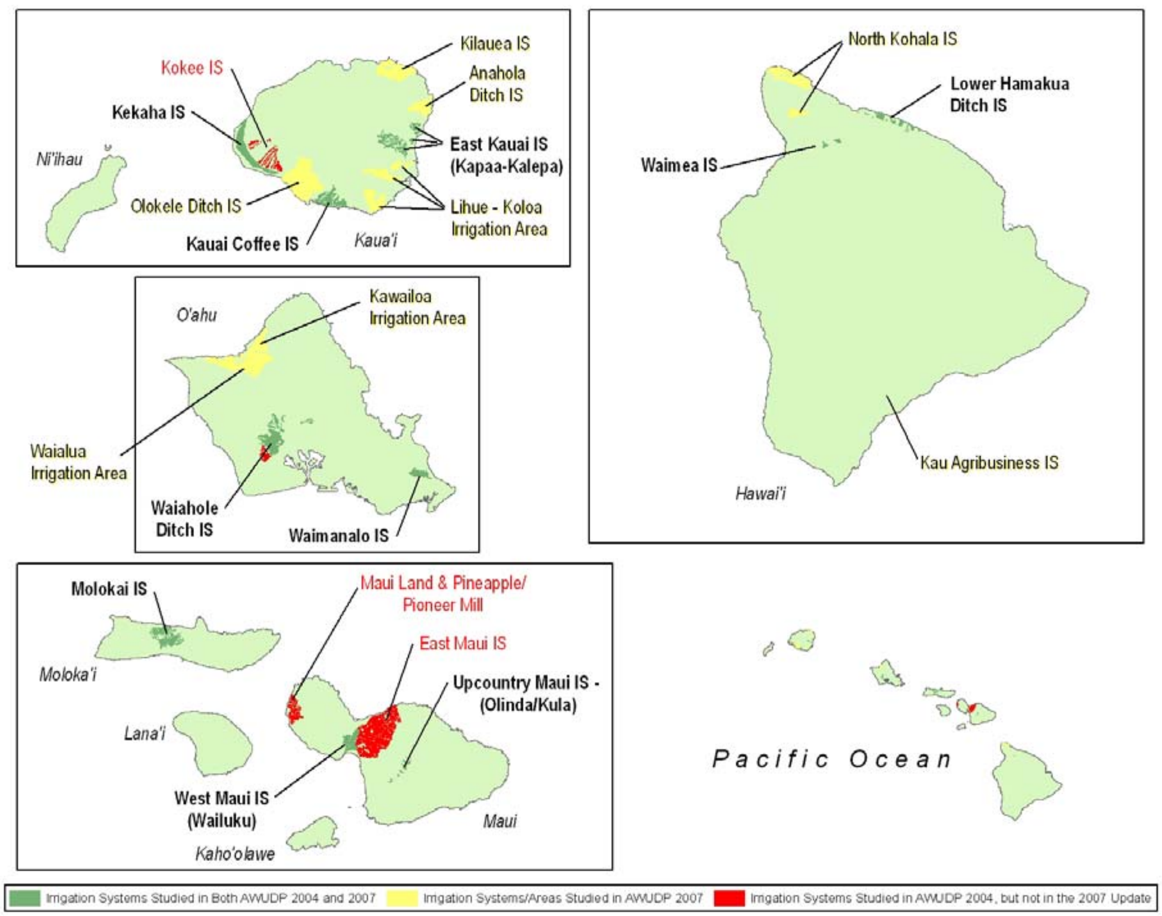


Figure ES1. Location of Irrigation Systems Covered by the 2004 and 2007 Updates.

Estimation of ***irrigation water requirements*** for 24 Hawaii crops at the 10 studied systems used a water budget approach. The model calculates crop irrigation requirements (IRR) based on site-specific historical rainfall and evaporation data, soil physical properties, crop-specific growth parameters, and water-use coefficients. The IRR for annual crops were computed for the dry and wet seasons, while perennial crop IRR were for the whole year. The same crops were used for each system to allow consistent comparisons across systems. The model assumed different farm water use efficiency rates based on the type of irrigation application technology (e.g., drip, micro-sprinkler) used by a particular crop. Possible system water losses in delivering irrigation water to a farm were not considered due to a lack of data. The project produced detailed tables of water budget components including IRR for various irrigation systems, crops, and growing seasons.

For the ***assessment of long-run agricultural potential*** at the 10 studied systems, the project developed an original model with 82 indicators measuring different aspects of the natural resource base, irrigation infrastructure and management, farming systems, and environmental problems. Irrigation system managers and users were interviewed to obtain detailed information about local conditions. This information was combined with data from GIS analyses, system records and other reports to rate each indicator. The 2004 study developed rehabilitation plans for 8 of the 10 systems. Where a proposed rehabilitation work is expected to directly improve water management and irrigation service, the respective indicator was re-rated to reflect with-rehabilitation conditions. An expert panel was surveyed using an iterative (Delphi) process to assess the relative importance of different indicators in determining a system's long-run potential. The panel estimated quantitative weights for indicator ratings from which a total score (maximum 100 points) was computed for each studied system, without and with rehabilitation. The panel also validated the model wherein a hypothetical system with "good" conditions scored around 90 points, while a "bad" but still operating system got about 40 points. The study provided a relative assessment of agricultural potential of the 10 studied systems based on their scores.

To develop ***projections of irrigation water demand*** to the year 2030, a Delphi survey of local economists identified the main drivers affecting growth of Hawaii's agricultural sector. From the panel's analysis, the project wrote qualitative descriptions of three future macroeconomic scenarios– Most Likely, Optimistic, and Pessimistic. A second Delphi panel of agriculturalists and agribusiness leaders estimated growth in agricultural acreages for 7 crop groups under these scenarios. The impact of proposed rehabilitation of studied irrigation systems was estimated from an observed relationship between system assessment scores and 2030 projected acreages. For bioenergy crops, potential acreage was projected from GIS analysis of former plantation areas with sufficient land and (if irrigated) water available for new enterprises. Farm-level water demands to 2030 were derived by multiplying projected crop acreages with the estimated water requirements based on the respective IRR coefficients for the 10 studied systems.

**Overview of Land and Water Resources**

Table ES2 summarizes agricultural land and irrigation water use in Hawaii, comparing total state resources with that of the 10 studied irrigation systems. Lands in the state Agricultural District total 1.9 million acres, of which 942,000 acres (49%) are classified by ALISH as prime, unique, or other important lands. Statewide, the 10 studied irrigation systems account for a small portion (<5%) of ALISH lands. However, the Molokai IS includes a significant share (20%) of the important agricultural lands on that island, as do the three studied systems on Kauai (18%).

The U.S. Geological Survey (USGS) estimates state and county water uses for different purposes every five years. These estimates include all major water uses and sources including non-potable waters (USGS, 2000). Table ES2 shows the latest data on irrigated area and water use, which includes farmland plus non-agricultural uses like landscaping, golf courses and parks. In 2000, a total 121,500 acres were irrigated with an average 363.5 million gallons per day (MGD) of water.

Table ES2. Agricultural Lands and Irrigation Use for Main Hawaiian Islands and 10 Studied Irrigation Systems

| | STATE RESOURCES | | | | STUDIED SYSTEMS | | |
|---|---|---|---|---|---|---|---|
| **Island** | **Agr. District** 100 ac. | **ALISH** 100 ac. | **Irrigated Area** 100 ac. | **Irr. Water Use** MGD | **System** | **Service Area** 100 ac. | **ALISH** 100 ac. |
| Kauai | 1,390 | 910 | 272 | 30.0 | East Kauai (Kapaa-Kalepa) | 59.2 | 55.1 |
| | | | | | Kauai Coffee | 46.6 | 43.7 |
| | | | | | Kekaha | 65.7 | 64.5 |
| | | | | | ***total Kauai*** | ***171.5*** | ***163.3*** |
| Oahu | 1,290 | 880 | 311 | 39.2 | Waiahole Ditch | 62.7 | 57.3 |
| | | | | | Waimanalo | 15.8 | 15.2 |
| | | | | | ***total Oahu*** | ***78.5*** | ***72.5*** |
| Maui | 2,450 | 1,490 | Maui 559 | County 274.6 | Upcountry Maui (Olinda-Kula) | 17.2 | 10.3 |
| | | | | | West Maui (Wailuku) | 64.3 | 63.0 |
| | | | | | ***total Maui*** | ***81.5*** | ***73.3*** |
| Molokai | 1,120 | 390 | | | Molokai | 98.9 | 77.8 |
| Lanai | 470 | 220 | | | n/a | | |
| Hawaii | 12,140 | 5,530 | 145 | 19.7 | Lower Hamakua Ditch | 46.6 | 39.5 |
| | | | | | Waimea | 13.7 | 12.4 |
| | | | | | ***total Hawaii*** | ***60.3*** | ***51.9*** |
| **State** | **19,310** | **9,420** | **1,215** | **363.5** | **Total** | **490.7** | **438.8** |

Sources: Hawaii DBEDT (2005) for state Agricultural District area and USGS (2000) for state Irrigated Area and Irrigation Water Use. Other data collected by this update.
*Average diversions, except Waiahole Ditch includes water returned to streams under CWRM order, Waimanalo is farm metered use, Molokai water measured at reservoir, and Waimea water entering reservoir. Where range given, island totals based on upper bound.

The studied irrigation systems have design capacities to divert and utilize large quantities of water. Maximum capacities at the seven larger systems total 437.4 MGD. Actual water use is typically much lower and the entire service area may not be irrigated, or even irrigable. Water measurement at the studied systems varies greatly in methods and accuracy. Ignoring these differences, recent surveys conducted by this study found water diversions from the 10 systems total 190.5 MGD. This is about half the USGS irrigation water estimate, though the latter has likely increased since 2000. The studied systems account for a large portion (>80%) of 2000 irrigation water use on all islands except Maui and Lanai. This highlights the importance of these systems in state water planning.

### Agricultural Land Suitability at Studied Systems

GIS was utilized to estimate ALISH areas at the 10 studied systems, information requested by the agencies that sponsored this study. The Land Capability Classification (LCC) system provides an alternative assessment of land suitability for agriculture. LCC layers were added to the GIS database for the studied irrigation systems.

LCC groups soil series into 8 suitability classes. Areas in the top two classes (I-II) do not have any serious conditions limiting agricultural use. Lands in the next two classes (III-IV) have one or more severe limitations (e.g., subject to erosion, poor drainage, stoniness, or drought) that reduce the choice of plants, require special management practices, or both, but are suitable for agriculture. Lower classes (V-VIII) are generally not suitable for growing crops but could be used for other purposes (e.g., grazing, woodland). Most soils are evaluated by LCC without and with irrigation. This provides one indicator of the importance of irrigation to an agricultural area.

Figure ES2 shows the portion of system service areas in LCC classes suitable for crop cultivation. A good majority of lands in all systems except Kekaha are in classes I-IV and suitable for growing some crop(s). Without irrigation, four of the 10 systems (East Kauai, Waiahole, Waimanalo, Waimea) have significant acreage in the top two classes. The availability of irrigation greatly increases top-rated lands for the systems on Kauai and Oahu, plus West Maui IS and Molokai. This provides farmers greater flexibility in selecting the most profitable crops, while holding down the cost of conservation measures. In contrast, irrigation does not greatly improve cropland suitability at the two Big Island systems.

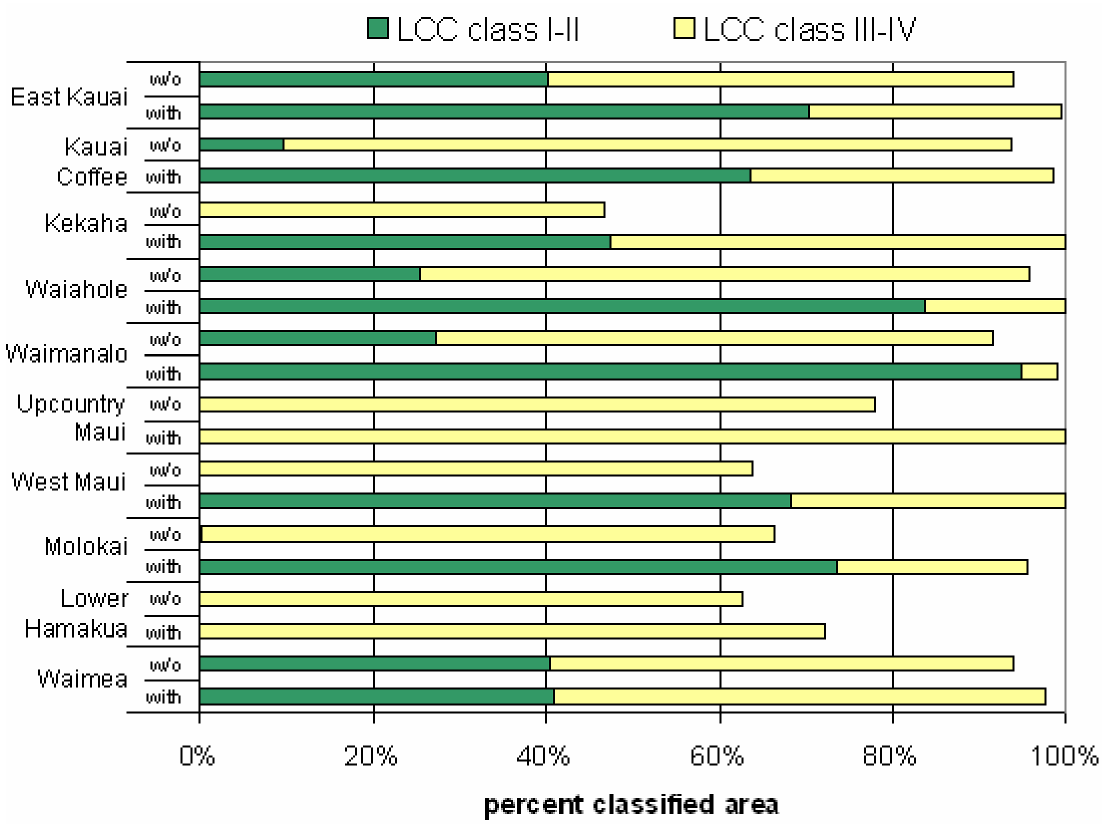


Figure ES2. Agricultural Land Suitability for 10 Studied Irrigation Systems, without and with Irrigation

**Previously Unstudied Irrigation Systems**

Hawaii has a long history of extensive development of agricultural irrigation, described by Wilcox (1996). The CWRM is developing a GIS database of irrigation facilities and related information to assist with water planning and management. Given funding limitations, the 2004 and 2007 studies focused on selected systems, which have become known as the "studied systems". For the 2007 study, agency staff identified another 11 irrigated areas to be added to the GIS database.

Table ES3 lists the previously unstudied systems, for which secondary data were collected and entered into GIS. Figure ES1 (above) shows the location of the irrigated areas. GIS computations estimated a total 69,700 acres of potential service area, excluding the Kau system for which little information is available. This is 42% larger than the service area of the 10 studied systems covered in this report. Due to a lack of funds, the project did not conduct any field studies to validate GIS information.

Table ES3. Delineation of Unstudied Irrigation Systems

| **Island** | **System Name** | **Former Plantation** | **Ditches** | **Potential Service Area** 1,000 ac. |
|---|---|---|---|---|
| Kauai | Kilauea IS | Kilauea Sugar | Kaloko & Puu Ka Ele | 7.9 |
| Kauai | Anahola Ditch IS | Lihue Plantation | Anahola | 4.3 |
| Kauai | Lihue-Koloa IA | Lihue Plantation<br>Grove Farm<br>Koloa Plantation | Upper & Lower Lihue<br>Upper & Lower Haiku<br>Waiahi-Kuia (Aqueduct)<br>Koloa-Wilcox | 10.9 |
| Kauai | Olokele Ditch IS | Olokele Sugar | Olokele-Koula | 16.0 |
| Oahu | Waialua IA | Waialua Sugar | Wahiawa, Helemano, Tanada, & Ito | 8.3 |
| Oahu | Kawailoa IA | Waialua Sugar | Opaeula & Kamananui | 4.8 |
| Hawaii | North Kohala IS | Kohala Sugar | Kohala & Kehena | 17.5 |
| Hawaii | Kau Agribusiness IS | Kau Sugar | n/a | n/a |
| | | | **total** | **69.7** |

**Wastewater Recyling and Reuse**

Reclamation of water from wastewater treatment plants can supplement natural water supplies. Reclaimed water can be used for certain irrigation purposes, subject to government regulation. In Hawaii, the state Department of Health (Hawaii DOH, 2002) classifies recycled water based on the level of treatment where

- R-3: secondary treatment without disinfection
- R-2: secondary treatment with disinfection
- R-1: tertiary treatment
- RO: reverse osmosis treatment.

Reclaimed waters treated to a higher level can be used for broader irrigation purposes with fewer restrictions on practices. Another study provides more details on reuse policy and recycling projects in Hawaii (Limtiaco Consulting Group, 2005).

For the 2007 updates, the sponsoring agencies requested that information on wastewater recycling facilities be collected and entered in a GIS database. Facility location and attributes were obtained for selected government-owned wastewater treatment plants, shown in Table ES4. The ten facilities (excluding Waianae) have a potential to supply almost 47 MGD, a significant portion (25%) of current water use (190.5 MGD in Table ES2) at the 10 studied irrigation systems.

Table ES4. Selected Government-Owned Wastewater Recycling Facilities and Potential Water Reuse at 10 Studied Irrigation Systems

| **Facility** | **Recycled Water** | | | **Potential Reuse at Studied Systems** |
|---|---|---|---|---|
| | **Quality** | **Capacity** MGD | **Avg. Use** MGD | |
| Lihu'e | R-2 | 2.4 | 2.4 | East Kauai IS (Kapaa-Kalepa) |
| Waimea | R-2 | 0.3 | 0.3 | Kekaha IS |
| Wailua | R-2 | 1.5 | 1.0-1.2 | East Kauai IS (Kapaa-Kalepa) |
| **total Kauai** | | **4.2** | | |
| Wahiawa | R-2 | 2.0 | n/a | Waiahole Ditch IS |
| Schofield Barracks | R-1 | 1.6 | n/a | Waiahole Ditch IS |
| Honouliuli | R-1<br>RO | 12.0<br>2.0 | n/a | Waiahole Ditch IS |
| Waianae | R-1 | planned | n/a | |
| **total Oahu*** | | **17.6** | | |
| Kaunakakai<br>**total Molokai** | R-2 | **0.3** | 0.008 | Molokai IS |
| Kihei | R-1 | 8.0 | 4.8 | |
| Lahaina | R-1 | 9.0 | 4.9 | |
| Wailuku-Kahului | R-2 | 7.8 | 5.0 | West Maui IS (Wailuku) |
| **total Maui** | | **24.8** | | |
| **Total** | | **46.9** | | |

Sources: Steve Parabicoli, Wastewater Division, County of Maui; Honolulu Board of Water Supply, C & C Honolulu; Wastewater Division, County of Kauai. *Excludes planned facility at Waianae.

Besides water availability, feasibility of reuse irrigation will depend on the cost of constructing new pipelines and delivering water to irrigated areas. There has been no systematic study of such costs in Hawaii. To address this issue, potential reuse zones up to 4 miles from a treatment facility were mapped with GIS. The 4-mile limit was based on current reuse areas and interviews with wastewater managers. The far right column of Table ES4 shows where reuse zones overlap with studied system service area. GIS overlay maps showed that most agricultural lands on Oahu, Maui and Molokai are more than 2 miles from a wastewater recycling facility. Kauai may offer the best potential for wastewater reuse, where some system lands are within 2 miles of the Wailua and Waimea treatment plants. But as shown in Table ES4, almost all current capacity at these facilities is being utilized. Without more information on the cost of recycled water capacity and distribution, this study could not evaluate the potential for increasing reuse irrigation at the studied systems.

### Crop Irrigation Water Requirements at Studied Systems

Irrigation water requirements at the 10 studied systems were estimated for selected crops. Based on historical climate (rainfall and evaporation) data, a water budget model computed values for IRR and other hydrologic components including crop evapotranspiration (ET), drainage, and runoff. The 10 studied systems displayed large variations in water budget estimates due to spatial variations in climate and soils.

Figure ES3 presents an example for sugarcane at two irrigation systems, East Kauai and Molokai, representing extremes in climate. Sugarcane had one of the highest potential ET among the crops studied. At the dryer Molokai system, crop ET is about 65% higher than at East Kauai. Even with less drainage and runoff, the Molokai irrigation water requirement is about 7 times higher on average. The figure also shows high variability in irrigation requirements from annual differences in weather. In the rainiest year, sugarcane at East Kauai would require almost no irrigation, while the minimum Molokai IRR is 25% below the average.

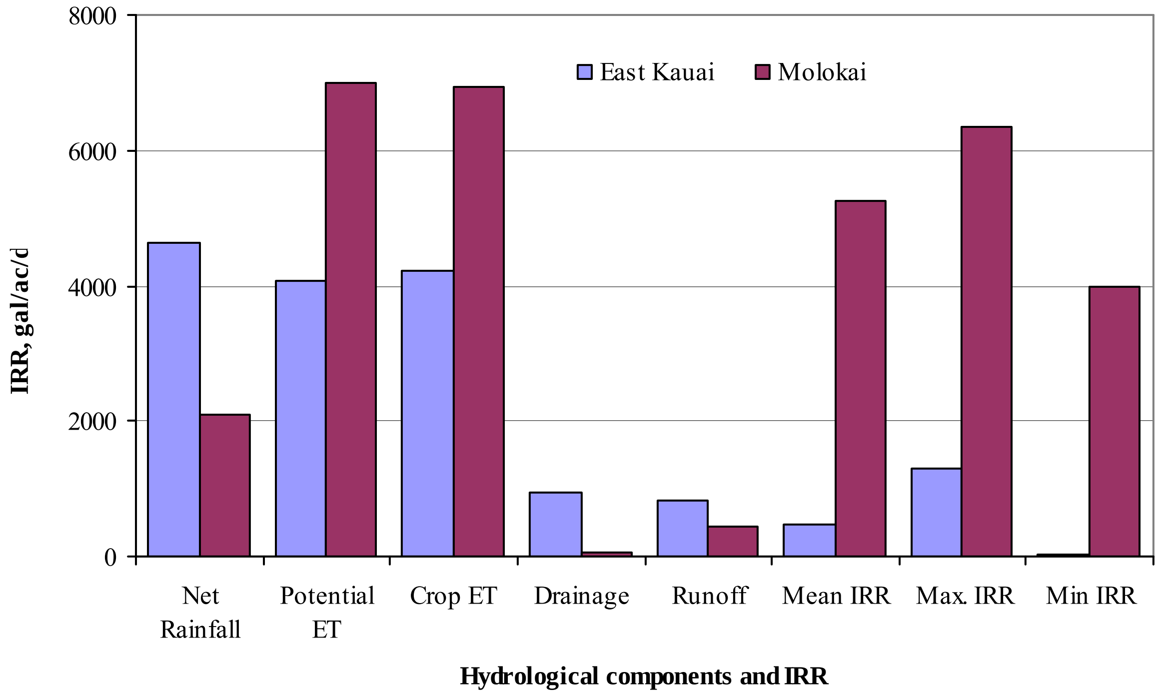


Figure ES3. Water Budget Components and IRR for Sugarcane in East Kauai and Molokai

Average daily irrigation water requirements for all studied systems are given in Table ES5 for selected crops. Figures ES4-ES5 show system differences for two annual crops (cabbage, seed corn) in the rainy season, and two perennial crops (young eucalyptus, sugarcane) over an entire year. Most of the spatial differences in IRR are mainly due to rainfall and ET spatial variations. Crops grown at systems located in windward areas (e.g., Waimanalo, East Kauai, Lower Hamakua) generally require less irrigation compared to leeward systems (e.g., Molokai, West Maui, Waiahole). Variations in IRR by crop are also important, reflecting differences in a plant's potential ET and management practices. Some crops like pineapple require very little irrigation. Wetland taro had the highest water requirements of the crops studied. The planting period can significantly change irrigation water requirements. IRR is typically lower in the rainy season (Oct.-Feb.) than in the dry season (April-Aug.).

This study estimated irrigation water requirements for selected systems and crops, with assumptions on cropping period, irrigation application technology, cultural and other management practices. The detailed IRR tables allow for consistent comparisons on water requirements across location and season. The quantitative values are believed to be sufficiently accurate and reliable for this purpose. The analysis is not intended as a recommendation on the crops that should be grown in any given situation. The calculated IRR values are used here to project future irrigation water demands for statewide water planning purposes. They do not represent actual nor recommended water use for any particular farm, which will vary with many factors.

Table ES5. Estimated Farm Irrigation Water Requirements at 10 Studied Irrigation Systems for Selected Crops (gallons/ac/day)

| Crop Type | Season (days) | Kekaha IS | Kauai Coffee IS | East Kauai IS | Waiahole IS | Waima-nalo IS | Molokai IS | West Maui IS | Up Country IS | Waimea IS | Lower Hamakua IS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Banana, ratoon | annual | 2230 | 2003 | 219 | 2247 | 811 | 4085 | 3696 | 1496 | 2268 | 740 |
| Cabbage | rainy (92) | 1120 | 880 | 239 | 1033 | 239 | 2304 | 1739 | 707 | 978 | 446 |
| Cabbage | dry (92) | 4011 | 3152 | 652 | 3620 | 1804 | 6054 | 5848 | 2630 | 2685 | 1924 |
| Seed, Corn | rainy (124) | 1137 | 984 | 218 | 1153 | 194 | 2565 | 2016 | 677 | 1516 | 347 |
| Seed, Corn | dry (123) | 4106 | 3512 | 772 | 3862 | 1919 | 6423 | 6138 | 2780 | 2959 | 2008 |
| Sugarcane, yr- 1 | annual | 3266 | 2970 | 523 | 3156 | 1315 | 5427 | 4868 | 2216 | 2882 | 1153 |
| Sugarcane, yr- 2 | annual | 2926 | 2611 | 345 | 2838 | 1115 | 4871 | 4433 | 1959 | 2603 | 934 |
| Sugarcane, ratoon | annual | 3386 | 3104 | 534 | 3288 | 1375 | 5627 | 5058 | 2312 | 3008 | 1208 |
| Coffee | annual | 3542 | 3148 | 425 | 3512 | 1510 | 5595 | 5244 | 2507 | 3071 | 1189 |
| Eucaluptus closed canopy | annual | 3964 | 3630 | 512 | 3860 | 1674 | 6279 | 5816 | 2849 | 3518 | 1345 |
| Eucalyptus young | annual | 1904 | 1436 | 14 | 1852 | 490 | 3049 | 3036 | 1189 | 1696 | 373 |
| Guava | annual | 3416 | 3014 | 299 | 3392 | 1332 | 5408 | 5082 | 2395 | 3019 | 989 |
| Kikuyu Grass | annual | 4227 | 3830 | 581 | 4203 | 1860 | 6652 | 6189 | 3049 | 3668 | 1562 |
| Ti | annual | 3816 | 3556 | 551 | 3899 | 1734 | 6211 | 5764 | 2827 | 3430 | 1370 |

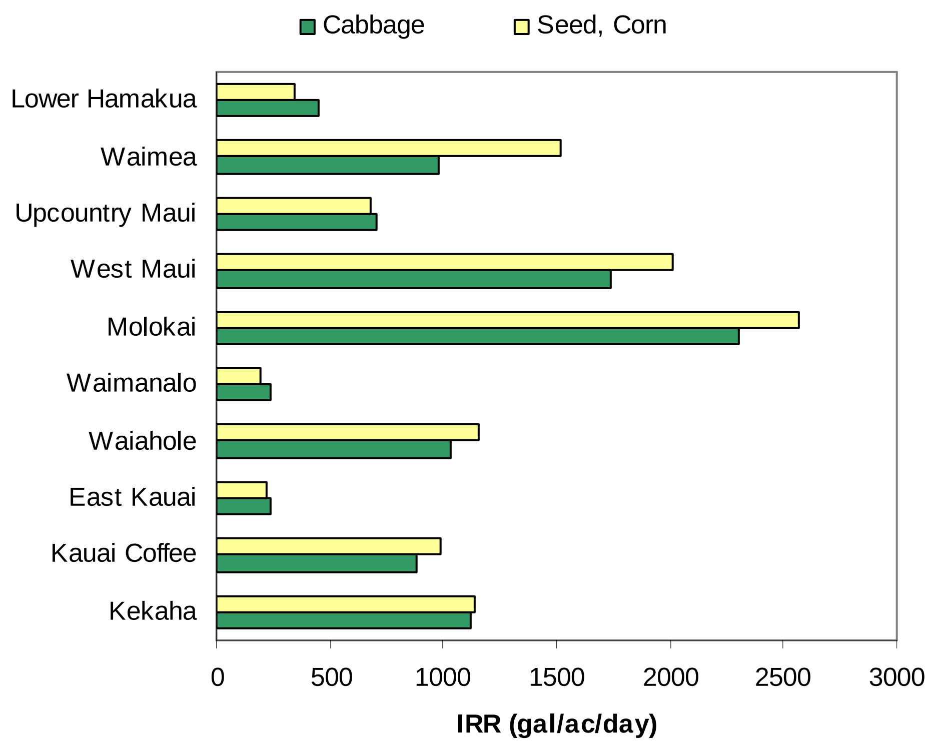


Figure ES4. Rainy season IRR for Two Annual Crops, 10 Studied Irrigation Systems

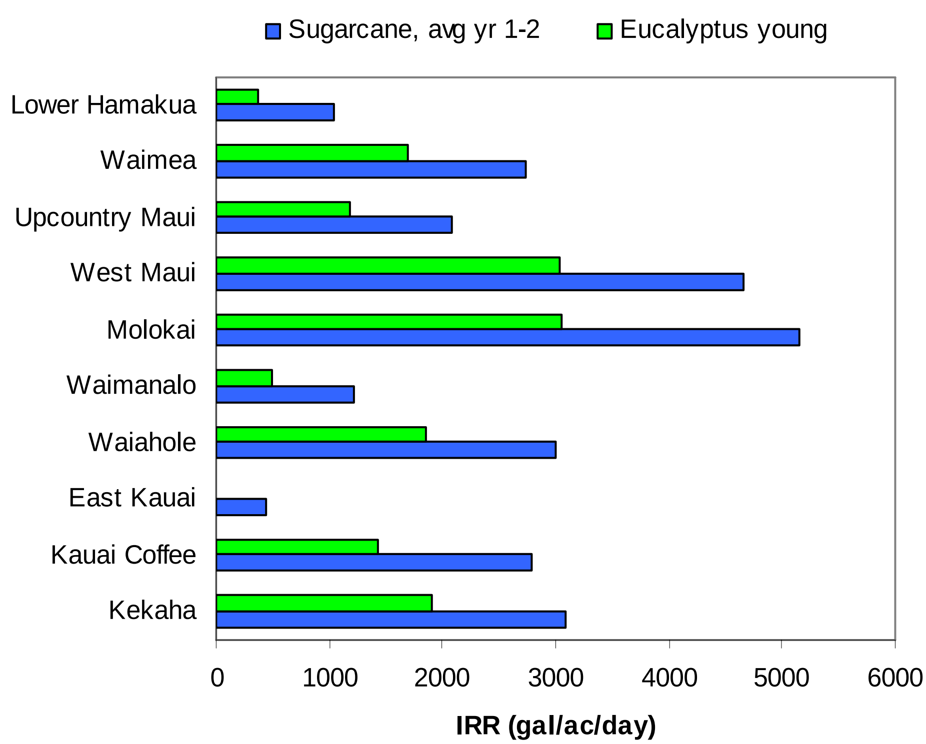


Figure ES5. Annual IRR for Two Perennial Crops, 10 Studied Irrigation Systems

**Long-Run Agricultural Potential of Studied Systems**

To assess the long-run agricultural potential of an irrigation system, the project developed the conceptual model shown in Figure ES6. The empirical model has seven major components (relative importance given in parentheses):

(a) Irrigation water supply (31%)
(b) Irrigation infrastructure and water delivery (19%)
(c) Irrigation system management (9%)
(d) Land resources (21%)
(e) Farm infrastructure and institutions (7%)
(f) Relations with non-agricultural community (7%)
(g) Environmental problems and limitations (6%).

The model was operationalized by 82 indicators developed and tested at the 10 studied irrigation systems. An expert panel estimated the relative importance of different factors, and validated the model for two hypothetical systems. Most of the data used to quantify indicator ratings came from visits to the irrigation systems conducted during the first half of 2006, supplemented by information in the the 2004 report. Note that our system visits occurred before the Oct. 2006 earthquake on the Big Island. The results presented below do not reflect earthquake damages at the Lower Hamakua and Waimea systems. Similiarly, the closure of the Del Monte pineapple plantation in early 2007 was not incorporated into analyses of the Waiahole Ditch system nor projections of future land and water use on Oahu.

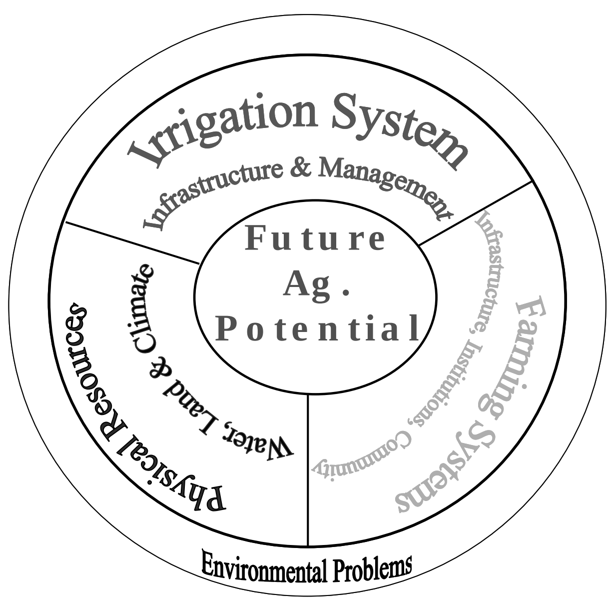


Figure ES6. Conceptual Model for Assessing Long-run Agricultural Potential of an Irrigation System

The GIS database provided other information used in the assessment. Table ES6 shows the irrigable lands in the 10 studied systems, which excludes areas that could not be used for any agricultural activity (e.g., gullies, houses), and the portion of irrigable acreage that is cultivated circa 2001. A large proportion (96%) of studied system service area is irrigable. Cultivated use is variable. Systems dominated by large farms (Kauai Coffee, Kekaha, West Maui) are utilizing large portions of their land resources. The cultivated portion is lowest at the Lower Hamakua and East Kauai systems, where small farms are still developing after recent plantation closures. Lands are available to expand Upcountry Maui irrigated area beyond current users.

The right hand side of Table ES6 presents the results from the model of long-run agricultural potential. Actual system scores fall within a fairly narrow range compared to those from the model validation exercise (hypothetical "good" 89-91 points, "bad" 34-44 points). All the studied systems have their positive and negative features. The Waimea IS received high ratings for most model components and had the top score, without and with rehabilitation. The next tier of systems–Waiahole, Kauai Coffee, Kekaha, West Maui–have large diversion capacities and are located in leeward areas, where the demand for irrigation water is high. Systems in the bottom tier (<65 points without rehabilitation) all experience serious problem(s) with water supply, which the expert panel judged the single most important determinant of long-run agricultural potential for an irrigated area.

Table ES6. Long-Run Agricultural Potential of 10 Studied Irrigation Systems, Without and With Rehabilitation

| **Irrigation System** | **LAND AREAS** | | | **AGR. POTENTIAL*** | | | |
|---|---|---|---|---|---|---|---|
| | **Service** | **Irrigable** | **Cultivated** | **w/o rehab** | | **with rehab** | |
| | 100 ac. | 100 ac. | % irrigable | score | rank | score | *rank* |
| East Kauai (Kapaa-Kalepa) | 59.2 | 59.0 | 26% | 63 | 8.5 | 72 | 5 |
| Kauai Coffee | 46.6 | 43.8 | 89% | 69 | 3 | 69 | 7 |
| Kekaha | 65.7 | 65.2 | 100% | 69 | 3 | 76 | 2.5 |
| Waiahole Ditch | 62.7 | 59.3 | 68% | 71 | 2 | 71 | 6 |
| Waimanalo | 15.8 | 14.6 | 56% | 56 | 10 | 68 | 8.5 |
| Upcountry Maui (Olinda-Kula) | 17.2 | 14.7 | 27% | 63 | 8.5 | 74 | 4 |
| West Maui (Wailuku) | 64.3 | 63.4 | 99% | 68 | 5 | 68 | 8.5 |
| Molokai | 98.9 | 97.3 | 27% | 64 | 6.5 | 76 | 2.5 |
| Lower Hamakua Ditch | 46.6 | 42.1 | 7% | 64 | 6.5 | 66 | 10 |
| Waimea | 13.7 | 13.2 | 56% | 77 | 1 | 82 | 1 |
| **Total/Average** | **490.7** | **472.6** | **56%** | **66** | | **72** | |

*Model scores (0-100 scale); ranks based on scores where midpoint value given for ties. No rehabilitation proposal by the 2004 report for Kauai Coffee and West Maui systems.

The 2004 study developed plans to rehabilitate infrastructure at 8 of the 10 studied systems. This would raise agricultural potential scores by an average 10% at these systems. Thus, rehabilitation is not a panacea that can overcome all system limitations. The Waiahole Ditch and Lower Hamakua systems have undergone rehabilitation within the past 10 years, so their scores do not increase much with additional improvements. The largest overall gains from rehabilitation are expected at the Upcountry Maui, Molokai, and Waimanalo systems.

The potential benefits from irrigation system rehabilitation will have to be weighed against the respective costs. Table ES7 shows estimated rehabilitation costs including deferred maintenance (AWUDP, 2004) compared to the respective increase in model scores. Rehabilitation would cost about $4,300 per acre on average, a relatively modest expenditure given the cost of agricultural land and farm operations in Hawaii. The Kekaha, Molokai, and East Kauai systems show the highest potential returns from the increase in long-run agricultural potential. Actual utilization of irrigable lands depends on future development of Hawaii agriculture, discussed in the following subsections.

Table ES7. Estimated Rehabilitation Costs and Potential Impacts at 8 Studied Irrigation Systems

| **Irrigation System** | **Rehab. Costs** | | **Increase in Agr. Potential** | |
|---|---|---|---|---|
| | **Total** $ millions | **Irrigable Area** $1,000/ac. | **Model Score** point change | **Impact:Cost** per $1,000/ac.* |
| East Kauai (Kapaa-Kalepa) | 10.5 | 1.8 | 9 | 5.1 |
| Kekaha | 7.3 | 1.1 | 7 | 6.3 |
| Waiahole Ditch | 11.3 | 1.8 | 0 | 0.0 |
| Waimanalo | 6.8 | 4.3 | 12 | 2.8 |
| Upcountry Maui (Olinda-Kula) | 9.3 | 5.4 | 11 | 2.0 |
| Molokai | 19.8 | 2.0 | 12 | 6.0 |
| Lower Hamakua Ditch | 9.6 | 2.1 | 2 | 1.0 |
| Waimea | 21.3 | 15.6 | 5 | 0.3 |
| **Average** | **12.0** | **4.3** | **7.3** | **1.7** |

*Increase in model score points (0-100 scale) divided by rehabilitation costs ($1,000/irrigable acre).

**Macroeconomic Scenarios and Drivers of Agricultural Growth**

Macroeconomic conditions will affect future development of Hawaii agriculture and the demand for irrigation water. An expert panel identified the following ten factors as important drivers (t=trend, u=uncertainty) for growth in Hawaii's agricultural sector through the year 2030:

- growth in U.S. gross domestic product (t)
- U.S. per capita incomes (t)
- value of the U.S. dollar (u)
- price of oil (t/u)
- number of visitors to Hawaii (t)
- Hawaii population growth (t)
- capital investment flows into Hawaii (t)
- cost of living and housing in Hawaii (t)
- investment in Hawaii transportation infrastructure (t)
- terrorist attack in Hawaii (u).

The panel developed a qualitative model explaining the linkages between the above factors and the supply and demand for Hawaii agricultural products. The planning scenarios outlined in Table ES8 were developed from this model and panel descriptors for a plausible range of conditions.

Table ES8. Key Features of Macroeconomic Scenarios

| **Scenario** | **General Economy** | **Hawaii Agriculture** |
|---|---|---|
| Most Likely | moderate growth<br>higher oil prices, fluctuating dollar<br>increasing local cost of living | modest growth<br>higher costs, shipping congestion<br>increased exports |
| Optimistic | strong growth<br>stabilized oil prices, depreciating dollar<br>higher local incomes | growth exceeds other sectors<br>new specialty crops & bioenergy industry<br>increased marketing efficiency |
| Pessimistic | stagnation with sharp downturns<br>volatile dollar, increasing oil prices<br>falling local incomes<br>credible terrorist threat | gradual decline<br>rising costs, low-cost competitors<br>slow export growth |

The macroeconomic panel's analysis found Hawaii agricultural development is closely tied to general economic conditions. The Most Likely scenario mirrors economic projections by Hawaii DBEDT (2004), where agricultural output is expected to grow 1.5-1.7% per year through 2030. Agricultural growth could be double that rate in the Optimistic scenario. In the Pessimistic scenario, Hawaii agriculture slides with the rest of the economy into an absolute decline. This range in possible futures highlights the importance of planning for change and continual monitoring of actual outcomes in the coming decades.

A second panel of agricultural experts assessed microeconomic drivers for growth in agricultural production across seven crop groups and five islands. Transportation and markets were identified as very important for most horticultural crops and for pasture. The availability and cost of water was somewhat important for all crop groups except pineapple and pasture. No island was identified as having a particular advantage or disadvantage in terms of water. Hawaii agriculture is market driven. Water supplies and irrigation infrastructure will probably not be primary determinants of actual growth in agricultural production.

**Land and Water Projections to 2030**

The update calls for projections of irrigation water demand to the year 2030 in 5-year increments, broken down by island, under different scenarios. The contract for this study also specified projections for the 10 studied systems. Given the lack of data on current water use, directly projecting irrigation demands would be problematic. Instead, this study projected agricultural acreages as an intermediate step. Water planners can more easily monitor resource utilization using the acreage projections since annual statistics are available for agricultural land use. The projections used actual crop acreages in 2004 as a base since these were the latest data released before the Delphi survey on expected growth rates.

The agricultural expert panel convened for the microeconomic analysis estimated growth rates for 7 crop groups and the percentage allocation across five islands. Statewide projections to 2030 for 6 crops groups (excluding pasture, which will probably not be irrigated) indicated an increase of 12,000-45,000 ac. under the three macroeconomic scenarios. Figure ES7 shows the acreage projections for the Most Likely scenario. Fruit and nut trees accounted for the largest (55%) share of the almost 27,000 ac. increase. The Big Island showed the greatest growth, adding just over 10,000 ac. The least growth is expected on Oahu.

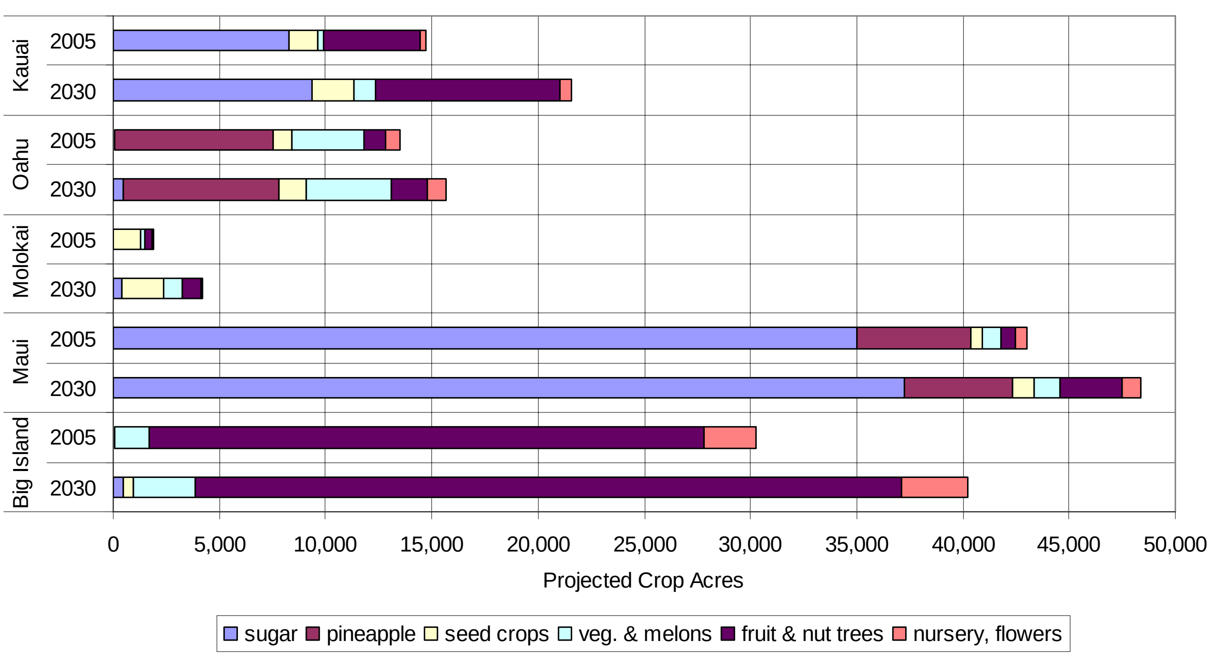


Figure ES7. Projected Crop Acreages for 5 Islands, Most Likely Scenario

Besides sugarcane already being grown in Hawaii, GIS analysis of former plantation lands identified another 53,000 ac. that might be utilized for new bioenergy crops. This is an optimistic projection. Large-scale bioenergy production in Hawaii is still speculative. A pessimistic outlook is that there will be little or no land for bioenergy crops beyond present sugarcane acreages. The study could not develop a most likely projection for bioenergy due to great uncertainties about this emerging industry.

Future agricultural demands for irrigation water were estimated from projected crop acreages. In the Optimistic scenario, state farm-level demand for water would grow to around 750 MGD in the year 2030 if all crops, pasture and potential bioenergy crops were fully irrigated. This is more than double the latest USGS estimate (Table ES2) of irrigation water use for all purposes. Figure ES8 shows water projections under the Most Likely Scenario plus potential bioenergy. For current crops, water demand was projected to grow an average 0.9% per year to 311 MGD in 2030. Hawaii showed the largest increase in demand, though other islands would also experience significant growth. Water for new bioenergy crops beyond current sugar operations could increase demand by another 35 MGD.

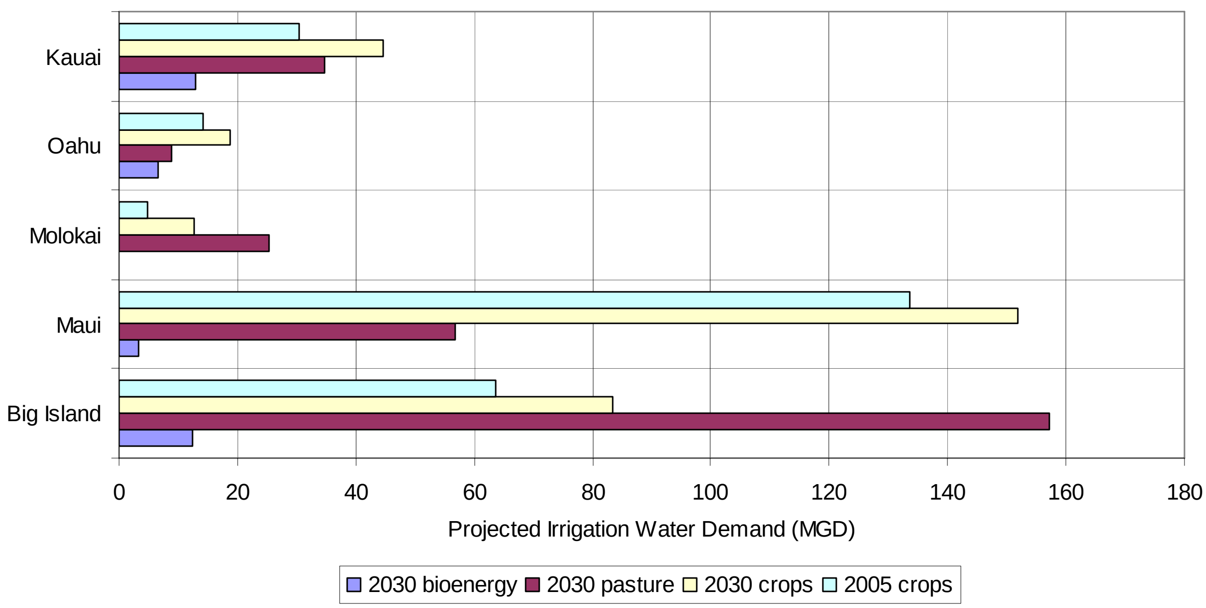


Figure ES8. Projected Irrigation Water Demand for 5 Islands, Most Likely Scenario and Potential Bioenergy

Figure ES9 shows current irrigation diversions and farm-level water demand projections for the studied irrigation systems. The greatest growth was projected at the Kekaha and Waimea systems. Demand for irrigation water would also increase sharply at the Molokai IS if it was rehabilitated. Data were not available to estimate system efficiency in delivering water to farms. Such analysis is needed in order to compare projected demands with available water resources.

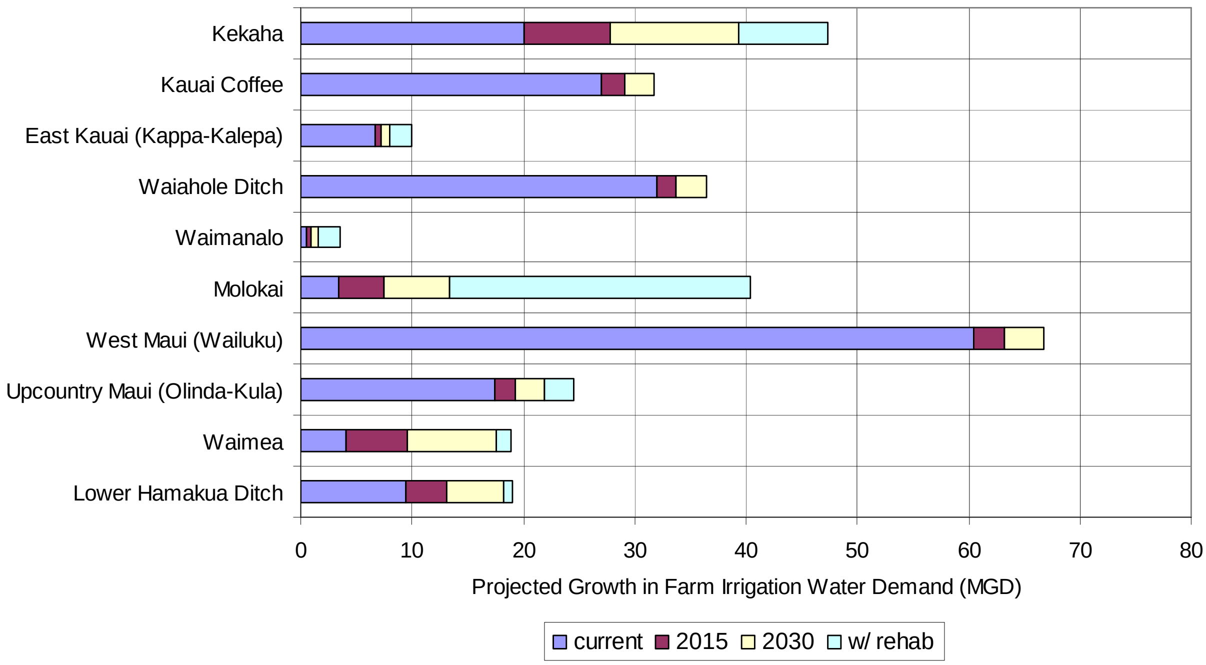


Figure ES9. Projected Growth in Farm Irrigation Water Demand at 10 Studied Irrigation Systems, Most Likely Scenario

**Implications for Water Planning**

Hawaii agriculture is expected to expand in coming decades. The demand for irrigation water will grow with it. Modest growth in the Most Likely scenario can probably be accommodated in most cases. The Optimistic scenario including potential bioenergy crops would bring 98,000 acres into production. The overall availability of agricultural land does not appear to be a serious constraint. The 2002 agricultural census (USDA, 2004) found about 100,000 acres of cropland were not being cultivated. If all agricultural lands were fully irrigated, agricultural water use could attain levels not experienced since the 1970s. At the other extreme, macroeconomic experts can foresee a Pessimistic scenario where local agricultural production falls. This could release water for other uses. However, the agriculturalists surveyed do not anticipate such a decline. Given present uncertainties about the future of Hawaii agriculture, water agencies and irrigators need to monitor changes as they unfold.

The 10 studied irrigation systems covered in this report represent a significant portion of Hawaii's irrigated agriculture and current water use. Projected growth could bring pressure on water resources at some locations, particularly the Molokai, Kekaha and Waimea systems. Analysis of proposed rehabilitation projects suggest greater returns from improvements at Kekaha and Molokai. However, just these two projects would cost about $30 million. Funding for such projects is not forthcoming, then projected growth in agricultural water demand could be left unmet, or new agricultural enterprises could seek other locations.

The potential service area of the 11 areas in the unstudied systems is about 70,000 ac. These lands and respective water resources offer an alternative to rehabilitating the studied systems. In the irrigation system assessment model developed here, the two components for water supply and land resources account for over half of a system's total score. The empirical model has 13 indicators to measure these components. Most of the data for these indicators can be collected from secondary sources or telephone interviews with system managers. Screening of these systems could help focus future studies on the best prospects.

Reuse of reclaimed wastewater is another possible means of satisfying growth in irrigation water demand. Analysis for the 10 studied systems showed some potential for agricultural use of reclaimed water, particularly on Kauai. However, sewage treatment plants are commonly sited in urban areas. Non-farm irrigated areas like golf courses and parks could be more easily served. The costs of construction, operations and maintenance of reclamation systems must be researched before firm recommendations and plans can be developed on reuse irrigation. Table 2-3 of the Limtiaco study lists the limitations on agricultural use of reclaimed water by crop type.

This study estimated future irrigation water demands at the farm level. Estimates of system efficiency in delivering water are needed to compare agricultural demands for water with available water resources. Site visits and interviews at the 10 studied systems found large differences in irrigation facilities, condition of infrastructure, irrigated area, irrigation practices, and cropping systems. We expect there are corresponding differences in system delivery efficiency. Current information is inadequate to quantify rates of system efficiency. This will require a special study, including water measurement under different conditions.

Estimated irrigation water requirements at the studied systems vary greatly by location, crop, season, and year. Spatial differences should be incorporated into county water planning. Estimates of crop and temporal variations could be useful for drought planning. Individual farmers can use this information to plan for their own farms.

# 1. INTRODUCTION

This is the final report of a study contracted to the College of Tropical Agriculture and Human Resource, University of Hawaii at Manoa by the Hawaii Department of Agriculture and Commission on Water Resources Management. Funding for this study was split between the Federal Government (U.S. Bureau of Reclamation) and the State of Hawaii. This report builds upon the work done in the 2004 (phase 1) Agricultural Water Use and Development Plan. The 2007 (phase 2) research was carried out between August 2005 and March 2007. The correspondence between sections of this report and the contracted scope of services is shown in Table 1.1.

Table 1.1. Correlation Between Report Section and Contract Scope of Services Items

| Final Report Section | Scope of Services | Scope Services Items |
|---|---|---|
| 2. Geographic Information Systems | 3.4 | Develop GIS Maps and spatial analysis for the services and surrounding areas of the 10 studied irrigation systems |
| | 3.5 | Develop GIS Maps for the 11 unstudied irrigation systems |
| 3. Crop Irrigation Water Duties | 3.1 | Develop crop irrigation water duties and irrigation system water demand methodology |
| 4. Assessment of Agricultural Potential for 10 Studied Irrigation Systems | 3.2 | Develop Hawaiian state agricultural industry water projections and outlooks |
| 5. Projecting Crop Acreages to Year 2030 | | |
| 6. Projected Crop Demands for Irrigation Water to Year 2030 | 3.3 | Develop irrigation system projections |

Section 2 describes the methods of spatial analysis used to develop GIS maps for (a) 10 studied irrigation systems, in more detail than Phase 1, and (b) 11 irrigated areas in unstudied irrigation systems which previously were unmapped. This corresponds to Scope of Services items 3.4 and 3.5.

Section 3 describes the method used to develop crop irrigation requirements (IRR) for major crop groups found in the studied and unstudied irrigation systems. This corresponds to Scope of Services item 3.1 A summary table of IRR coefficients is presented in the section and is used in Section 6 to create scenarios of future water demand, by island and by irrigation system. While the coefficients are estimated for specific regions, the methodology employed can be used to estimate crop irrigation requirements in other agricultural production areas in Hawaii.

Section 4 describes the conceptual model for assessing the long run agricultural potential for irrigated systems in Hawaii. A quantitative model of irrigation system performance was developed and a Delphi panel of experts in irrigation systems verified the estimates and defined the relative weights of the factors. The irrigation system model was estimated and verified for the 10 studied systems, with and without rehabilitation.

Section 5 reports on long run projections of crop acreages by island and by studied irrigation system, with and without rehabilitation. Delphi panels of experts in macroeconomic development and in agricultural development were used to determine growth rates for crop groups over the next 25 years. Sections 4 and 5 correspond to Scope of Services item 3.2.

Section 6 reports the long run projections of crop demand for irrigation water by island and by studied irrigation system. This section brings together the empirical results of Sections 3, 4 and 5, and corresponds to Scope of Services item 3.3.

Each of the major sections above (Sections 3-6) has a concluding section that provides a short overview of what was presented. Section 7 provides key findings and recommendations of the study and discusses some qualifications and other issues that have arisen during the conduct of the study.

# 2. GIS-BASED SPATIAL ANALYSIS MAPS

In this section, we present GIS maps and acreage estimates of the 21 irrigation systems/areas listed in the Table ES1. All the GIS maps are found in a separate volume entitled, "*Agricultural Water Use and Development Plan, 2007 Update: GIS Maps*."

## 2.1. The Irrigation Systems Studied in the 2004 and 2007 Updates

Five overlay analyses were performed for the service and surrounding areas of the 10 irrigation systems studied in the 2004 and 2007 updates. The purpose of the analyses was to obtain baseline agricultural land maps and acreage estimates as specified in Scope of Services. The baseline information identified in the contract were: (1) Agricultural Lands of Importance to the State of Hawaii (ALISH), (2) soil types, (3) crop types (current land uses) , (4) depiction of most likely as well as optimistic and pessimistic build out scenarios of agricultural lands, or projected crop acreages, and (5) potential wastewater sources for agricultural irrigation.

### 2.1.1. Agricultural Lands of Importance to the State of Hawaii (ALISH)

A GIS layer of ALISH was obtained from Hawaii State GIS Program at the State of Hawaii's Office of Planning (http://www.hawaii.gov/dbedt/gis/). This ALISH GIS layer was a digitized version of the original ALISH hand-drafted and complied in 1977 (Hawaii State Department of Agriculture, 1977). No attempt was made to update ALISH because our visual inspections of airborne and satellite imagery acquired in or after 2000 showed that most of the service and surrounding areas of the 10 irrigation systems were still in agricultural uses or idle. The airborne and satellite images inspected included Emerge, IKONOS, and Landsat ETM+.

Three ALISH classes out of the four, "Prime Agricultural Lands," "Unique Agricultural Lands," and "Other Agricultural Lands," were extracted from the ALISH GIS layer and were overlaid onto each of the 10 irrigation systems' service areas. The following table summarizes the acreage estimates from the overlay analyses. The corresponding maps are found as Maps 1A – 10A in "*Agricultural Water Use and Development Plan, 2007 Update: GIS Maps*."

Table 2.1. ALISH Acreage Estimates for the 10 Studied Irrigation Systems (Units: 100 acres)

| Irrigation System Name/ Service Area | Island | ALISH Prime | ALISH Unique | ALISH Other | ALISH Total | ALISH within Service Area (%) |
|---|---|---|---|---|---|---|
| East Kauai (Kapaa-Kalepa) | Kauai | 50.1 | – | 5.0 | 55.1 | 93 % |
| Kauai Coffee | Kauai | 40.8 | – | 2.9 | 43.7 | 94 % |
| Kekaha | Kauai | 49.9 | – | 14.5 | 64.5 | 98 % |
| Waiahole Ditch | Oahu | 51.2 | – | 6.0 | 57.3 | 91 % |
| Waimanalo | Oahu | 11.6 | – | 3.6 | 15.2 | 96 % |
| Upcountry Maui (Olinda-Kula) | Maui | 0.6 | – | 9.7 | 10.3 | 60 % |
| West Maui (Wailuku) | Maui | 40.9 | – | 22.1 | 63.0 | 98 % |
| Molokai | Molokai | 74.1 | – | 3.6 | 77.8 | 79 % |
| Lower Hamakua Ditch | Hawaii | 29.7 | – | 9.8 | 39.5 | 85 % |
| Waimea | Hawaii | 10.3 | – | 2.1 | 12.4 | 91 % |

### 2.1.2. Soil Types (Land Capability Classes)

The latest version of the U.S. General Soil Map of Hawaii was obtained through the USDA Geospatial Data Gateway (http://datagateway.nrcs.usda.gov/). In Hawaii, there exist a large number of soil series (e.g., 44 soil series in Oahu, 49 soil series in Maui, and 71 soil series in Big Island), which made it difficult to comprehend spatial trends of soil types when soil series were used as the mapping unit. Hence, we used Land Capability Classification (LCC) to group soil series into a smaller number of categories. LCC shows, in a general way, the suitability of soils (or landscapes) for most kinds of crops (USDA Soil Conservation Service, 1972), appropriate for the purposes of this study.

Most of soil series have been assigned a LCC class for both irrigated and non-irrigated conditions. LCC GIS layers were created for both irrigated and non-irrigated conditions. The following tables summarize the acreage estimates from overlay analyses of the non-irrigated and irrigated LCC layers on the service areas. The corresponding maps for non-irrigated LCC are found as Maps 1S – 10S in "*Agricultural Water Use and Development Plan, 2007 Update: GIS Maps*."

Table 2.2. LCC (Non-irrigated) Acreage Estimates for the 10 Studied Irrigation Systems (Units: 100 acres)

| Irrigation System Name/ Service Area | Island | I | II | III | IV | V | VI | VII | VIII | Un-classified |
|---|---|---|---|---|---|---|---|---|---|---|
| East Kauai (Kapaa-Kalepa) | Kauai | – | 23.8 | 27.7 | 4.1 | 0.1 | 1.0 | 2.1 | 0.4 | < 0.1 |
| Kauai Coffee | Kauai | – | 4.6 | 5.2 | 33.7 | – | 1.3 | 1.1 | 0.6 | 0.2 |
| Kekaha | Kauai | – | – | – | 26.3 | 18.1 | 11.5 | – | 0.4 | 9.4 |
| Waiahole Ditch | Oahu | – | 15.9 | 27.8 | 16.2 | – | 0.3 | 2.3 | 0.1 | 0.2 |
| Waimanalo | Oahu | – | 4.3 | 9.7 | 0.4 | – | 0.7 | 0.5 | <0.1 | < 0.1 |
| Upcountry Maui (Olinda-Kula) | Maui | – | – | 1.0 | 12.4 | – | 2.7 | 1.1 | – | – |
| West Maui (Wailuku) | Maui | – | – | 3.1 | 37.9 | – | 19.3 | 4.0 | – | < 0.1 |
| Molokai | Molokai | – | 0.2 | 19.4 | 45.2 | – | 28.4 | 4.3 | – | 1.1 |
| Lower Hamakua Ditch | Hawaii | – | – | 9.5 | 19.7 | – | 10.7 | 6.4 | – | – |
| Waimea | Hawaii | 0.3 | 5.3 | 7.3 | – | – | – | 0.5 | – | – |

Table 2.3. LCC (Irrigated) Acreage Estimates for the 10 Studied Irrigation Systems (Units: 100 acres)

| Irrigation System Name/ Service Area | Island | I | II | III | IV | V | VI | VII | VIII | Un-classified |
|---|---|---|---|---|---|---|---|---|---|---|
| East Kauai (Kappa-Kalepa) | Kauai | – | 23.9 | 8.0 | 2.0 | – | 0.2 | – | – | 25.4 |
| Kauai Coffee | Kauai | <0.1 | 28.1 | 12.8 | 2.7 | – | 0.7 | – | – | 3.0 |
| Kekaha | Kauai | 24.4 | 2.0 | 25.7 | <0.1 | – | – | – | – | 13.6 |
| Waiahole Ditch | Oahu | 23.1 | 26.4 | 7.4 | 2.9 | – | 0.1 | – | – | 2.7 |
| Waimanalo | Oahu | 0.1 | 12.3 | 0.2 | 0.3 | – | <0.1 | – | – | 2.8 |
| Upcountry Maui (Olinda-Kula) | Maui | – | – | 1.0 | 11.4 | – | 0.3 | – | – | 4.5 |
| West Maui (Wailuku) | Maui | 21.2 | 19.9 | <0.1 | 0.6 | – | – | – | – | 22.5 |
| Molokai | Molokai | 23.2 | 44.2 | 15.5 | 4.7 | – | 3.7 | – | – | 7.4 |
| Lower Hamakua Ditch | Hawaii | – | – | 7.6 | 13.1 | – | 7.6 | – | – | 17.9 |
| Waimea | Hawaii | 5.3 | – | 7.3 | – | – | – | – | – | 0.8 |

### 2.1.3. General Crop Types (Land Cover/Land Use Types)

Land cover/land use maps were created by classifying fine-resolution Emerge and/or IKONOS remotely-sensed images (acquired in or after 2000). The images were first segmented and then all the segments were classified based on their colors and textures. Finally, ground surveys were conducted to identify the surface cover (land use) types for each of the classes. Details of GIS layer sources and methods used for land cover classification are described in Appendix 9.1.

Table 2.4 summarizes acreage estimates of general land use types. Five classes have been defined: (1) cultivated, (2) grazing, (3) cultivable, (4) non-cultivable, and (5) non-irrigable. "Non-irrigable" has been defined as areas that are unlikely to be used for any agricultural activities, e.g., cliffs, gullies, rock outcrops, residential areas, etc. The other four classes can be considered sub-categories of "Irrigable," or not "Non-irrigable." "Cultivable" were areas that were not currently used for any agricultural activities, including forested areas, rangelands (shrublands), and abandoned areas. If an area (or a segment) was not identified either "cultivated", "grazing", or "cultivable", it was classified as "non-cultivable." The corresponding maps are found as Maps 1 – 10 in this Update under GIS Maps.

Table 2.4. Acreage Estimates of General Crop Types for the 10 Studied Irrigation Systems (Units: 100 acres)

| Irrigation System Name/ Service Area | Island | Cultivated | Grazing | Cultivable | Non-cultivable | Non-irrigable |
|---|---|---|---|---|---|---|
| East Kauai (Kappa-Kalepa) | Kauai | 15.3 | 43.8 | – | – | 0.2 |
| Kauai Coffee | Kauai | 39.0 | 4.9 | – | – | 2.8 |
| Kekaha | Kauai | 65.2 | – | – | – | 0.5 |
| Waiahole Ditch | Oahu | 40.0 | – | 18.8 | 0.5 | 3.4 |
| Waimanalo | Oahu | 8.1 | 1.1 | 5.2 | 0.2 | 1.2 |
| Upcountry Maui (Olinda-Kula) | Maui | 4.0 | 2.5 | 8.0 | 0.2 | 2.5 |
| West Maui (Wailuku) | Maui | 63.2 | – | 0.1 | < 0.1 | 0.9 |
| Molokai | Molokai | 26.7 | 6.8 | 57.9 | 5.8 | 1.6 |
| Lower Hamakua Ditch | Hawaii | 3.1 | 36.7 | 2.4 | – | 4.5 |
| Waimea | Hawaii | 7.4 | 5.7 | < 0.1 | – | 0.5 |

### 2.1.4. Projected Crop Acreage Maps for the 10 Irrigation Systems

Maps of projected crop acreages for all crops including bioenergy, but pasture, for likely, pessimistic and optimistic scenarios were created for years 2005 – 2030 at 5-year intervals for each of the 10 irrigation systems and provided as Maps 1P – 10P in this Update under GIS Maps. The projection methods used and projected acreage values are presented in Section 5 and Appendix 9.21, respectively, of this Update. GIS was used to identify locations within a service area where likely to be cultivated or abandoned. Details of the GIS overlay analysis method are described in Appendix 9.2.

This GIS overlay analysis was limited only to the service areas. In any instances where the projected acreages exceeded the service areas, the analysis did not expand to map the projected acreages beyond the service areas (i.e., less acreages depicted in the map than the actual projected acreages). For example, 100% of the Kekaha service area (irrigable) was cultivated (Table 2.4) and, thus, no map was created for the irrigation system.

### 2.1.5. Wastewater Reuse Potential for the 10 Irrigation Systems

Potential wastewater reclamation and reuse sources for agricultural irrigation in the service areas of the 10 studied systems were assessed. Table 2.5 lists the county-owned wastewater recycling facilities (WWRFs) and quality of their recycled water, their capacity (sources: Steve Parabicoli, Wastewater Division, County of Maui; Honolulu Board of Water Supply, C & C Honolulu; Wastewater Division, County of Kauai), and their potential for agricultural irrigation. The other facilities listed in the 2004 Hawaii Water Reuse Survey and Report were not included in our assessment either because they are privately-owned, because their capacity was too small and could not be expected to increase (e.g., 0.0001 MGD for Haleakala National Park WWRF), or because they were too far from the service areas.

WWRF's potential to deliver reclaimed water to each of the service areas were assessed by linear, horizontal distance. The distance was divided into five classes: (1) .25 miles, (2) 0.5 miles, (3) 1 miles, (4) 2 miles, and (5) 4 miles, and a series of buffer zones corresponding to these distances were created. We attempted to estimate "cost distances" which account for topographic relief in estimating distances; however, this would involve the estimation of engineering methodology and costs and thus was not pursued further. Maps 22 – 27 in this Update under GIS Maps graphically show proximity of the service areas to nearby WWRFs.

Table 2.5. County-owned Wastewater Recycling Facilities (WWRFs) and Their Potential for Agricultural Irrigation in the Service Areas (S.A.) of the 10 Studied Irrigation Systems

| Facility | Island | Quality | Capacity§ | Potential S.A. |
|---|---|---|---|---|
| Lihu'e WWRF (County of Kauai) | Kauai | R-2 | 2.4 MGD (2.4 MGD) | East Kauai IS (Kapaa-Kalepa) |
| Waimea WWRF (County of Kauai) | Kauai | R-2 | 0.3 MGD (0.3 MGD) | Kekaha iS |
| Wailua WWRF (Country of Kauai) | Kauai | R-2 | 1.0-1.2 MGD (1.5 MGD) | East Kauai IS (Kapaa-Kalepa) |
| Wahiawa WWRF (C & C Honolulu) | Oahu | R-2 (R-1)* | 2.0 MGD (n/a) | Waiahole Ditch IS |
| Schofield Barracks WWRF, Army | Oahu | R-1 | 1.6 MGD (n/a) | Waiahole Ditch IS |
| Honouliuli WWRF (C & C Honolulu) | Oahu | R-1/RO | 12 / 2 MGD (n/a) | Waiahole Ditch IS |
| Waianae WWRF (C & C Honolulu) | Oahu | R-1 (planned) | (planned) | – |
| Kaunakakai WWRF (County of Maui) | Molokai | R-2 | .008 MGD (.3 MGD) | Molokai IS |
| Kihei WWRF (County of Maui) | Maui | R-1 | 4.8 MGD† (8 MGD) | – |
| Lahaina WWRF (County of Maui) | Maui | R-1 | 4.9 MGD† (9 MGD) | – |
| Wailuku-Kahului WWRF (County of Maui) | Maui | R-2 | 5 MGD (7.8 MGD) | West Maui IS (Wailuku) |

(Sources: Steve Parabicoli, Wastewater Division, County of Maui; Honolulu Board of Water Supply, C & C Honolulu; Wastewater Division, County of Kauai)

§ The numbers in parentheses are the maximum dry weather capacity.

* Wahiawa WWRF produces "R-1 like" R-2 reclaimed water; however, it does not qualify as an R-1 system (DLNR-CWRM, 2005).

† The actual reuse amounts of reclaimed water are seasonally highly variable in these WWRFs.

## 2.2. The 11 Irrigation Systems/Areas Identified in Chapter 3 of AWUDP 2004

GIS maps for the 11 irrigation systems/areas identified in Chapter 3 of AWUDP 2004 were developed. As specified in Scope of Services, the maps show locations, types, and status of all the irrigation infrastructure for the 11 irrigation systems that were found in existing documents. These maps are included as Maps 11-21 in this Update under GIS Maps.

The work also resulted in the creations of four sets of vector GIS layers: (1) one point vector layer containing diversion locations, (2) a set of line vector layers containing locations, status, owners, and system capacities of ditches, tunnels, flumes, and pipelines, (3) a set of polygon vector layers containing reservoirs and their status, owners, and system capacities, and (4) another set of polygon vector layers for potential service areas. The data structures or format of these GIS layers are described in Appendix 9.3.

Acreage estimates of the potential service areas of the 11 irrigation systems are presented in Table 2.6. In brief, these potential service areas were derived based on (1) land ownerships (current or inherited from former sugarcane companies), (2) elevation (since most of the irrigation systems are gravity-fed), (3) current land use, and (4) historical spatial extent and distribution of sugarcane fields. Detailed description of the methods used for delineating these areas is given in Appendix 9.3.

Table 2.6. Acreage Estimates of the Potential Service Areas of the 11 Unstudied Irrigation Systems Identified in Chapter 3 of AWUDP 2004 (Units: 1,000 acres)

| Irrigation System Name | Names of Ditches | Island | Service Area (Acreage) |
|---|---|---|---|
| Kilauea Irrigation System (IS) | Kaloko & Puu Ka Ele Ditches | Kauai | 7.9 |
| Anahola Ditch IS | Anahola Ditch | Kauai | 4.3 |
| Lihue-Kola Area | Upper & Lower Lihue Ditches, Upper & Lower Haiku Ditches, Waiahi-Kuia Aqueduct, Koloa-Wilcox Ditch | Kauai | 10.9 |
| Olokele Ditch IS | Olokele-Koula Ditch | Kauai | 16.0 |
| Waialua Area | Wahiawa, Helemano, Tanada, & Ito Ditches | Oahu | 8.3 |
| Kawailoa Area | Opaeula & Kamananui Ditches | Oahu | 4.8 |
| North Kohala IS | Kohala & Kehena Ditches | Hawaii | 17.5 |
| Kau Agribusiness IS* | – | Hawaii | – |

*Due to the difficulty in locating the irrigation infrastructure, the potential service area of this system was not investigated.

### 2.2.1. Status of Selected Irrigation Systems

***Kilauea IS: Kaloko and Puu Ka Ele Ditches***

In March 2006, Kaloko dam failed and breached, killing 7 people. Lawsuits abound regarding the incident, and as a result, no one involved in the system will disclose any information regarding its ownership. Kaloko Reservoir's current capacity is approximately 1/3 its capacity prior to the breach, and it is fed by Kaloko Ditch and Moloaa Ditch. Moloaa Ditch does not appear on any maps, but it has a capacity of 30 mgd and an average flow of ½ - 1 mgd.

***Anahola Ditch IS***

The Anahola portion of the former Lihue Plantation was abandoned in the 1980s. Drip irrigation was utilized in the lower lands, including the portion of the Lower Anahola Ditch flowing to DHHL lands. Much of the system consists of redwood flumes which have rotted and been damaged extensively by hurricanes Iwa and Iniki and by floods in 1991. Kawano Ditch is in poor condition as well due to landslides and fallen trees. The Lower Anahola Ditch is worse. The Upper Anahola Ditch intake is plugged by boulders. The tunnel is functional, but the ditch connecting the tunnel to Kaneha Reservoir is deteriorated beyond use.

***North Kohala IS: Kohala Ditch***

The Kohala Ditch suffered extensive damage in the 6.7 and 6.0 magnitude earthquakes on October 15, 2006. Ditch capacity prior to the earthquake was approximately 20 mgd. There is no water flowing through the ditch now because the Honokane West Branch flume was destroyed by a landslide in the earthquake, severing the system from its primary intake. The area is still considered unstable and unsafe for exploration. Only diversions 3 and 6-9 are still operating and providing a few users with some water.

***North Kohala IS: Kehena Ditch***

Kehena Ditch legally does not exist because its easements were expunged in 1969 when the sugar plantation closed. Only a portion of the ditch is currently maintained. After the earthquake October 15, 2006, water still flows. Operators have not checked every tunnel since the earthquake, but water is still flowing.

***Kau Agribusiness IS***

The Kau sugar plantation was unirrigated. USGS has no record of irrigation ditches in the Kau district.

# 3. CROP IRRIGATION WATER DUTIES

## 3.1 Overview

The (gross) Irrigation water requirement (*IRR*) for crop production is the amount of water, in addition to rainfall, that must be applied to meet a crop's evapotranspiration needs without significant reduction in yield. The *IRR* were determined for the highest value crops grown in Hawaii in the 10 selected irrigation systems located on major Islands of Hawaii using available historical climate data, soil physical properties, crop-specific water use coefficients, and average growing period of the crop. The *IRR* were determined for each selected annual crop for two distinct periods; the dry and wet seasons of the year, whereas for perennial crops *IRR* were determined for the whole year only. The *IRR* were calculated based on a daily water budget approach for each crop using system specific historical daily climate data. The daily water budget is formulated as water input minus water output equals to change in the water storage in the root zone. Water inputs are rainfall and irrigation. Water outputs are runoff, crop evapotranspiration, and deep percolation or drainage. Historical daily rainfall and reference crop evapotranspiration data were obtained for at least one location per system for each of the 10 systems. Reference crop or potential evapotranspiration ($ET_O$) was calculated using daily pan evaporation measurements or estimated from minimum and maximum temperature measurements. Runoff ($Q_R$) was calculated using Soil Conservation Service (SCS) curve number method and daily rainfall data. Crop evapotranspiration ($ET_C$) was calculated by multiplying crop coefficient ($K_C$) with $ET_O$. Drainage ($Q_D$) was calculated internally during daily water budget calculations as any amount of water exceeding field capacity after soil water redistribution process ends. Subsequently *IRR*, the only unknown in the water budget approach, was calculated for each day of the historical climate data period. Then a statistical analysis was performed on the calculated long term historical daily *IRR* data set. These daily values were summed along a given crop growth season to obtain seasonal or annual average, maximum, and minimum irrigation requirements. Calculated *IRR* values showed various differences both spatially and temporally between irrigation systems based on the location of each individual system, the type of crops, and the timing of the planting period (the growing season).

## 3.2 Introduction

A plant irrigation water requirement is the depth of water required to replenish the soil water content to field capacity in the irrigated crop root zone. Maintenance of adequate soil water content through the crop growing season is necessary for optimum plant growth and yield. In most cases, soil water content is at optimum level only for a short period during the growing season; hence, irrigation is needed to maintain adequate soil water availability. The purpose of managed irrigation is to optimize water spatial and temporal distribution, enhance crop growth and yield, and increase economic returns. In Hawaii, existing water management of agricultural industry is mainly based on the irrigators' best judgment and experience of trial and error, which generally results in excess irrigation. Excess water losses below the root zone due to excessive irrigation carry with them dissolved fertilizers and pesticides beyond their target area resulting in substantial increases in maintenance costs and environmental hazards. Optimum irrigation water management is critical in any effort to increase Hawaiian agricultural industry's net economic returns and reduces potential groundwater quality impairment.

The main goal of this part of the project was to calculate *IRR* requirement which must be applied to prevent yield-reducing water stress in each system during crop growth periods. The *IRR* were determined based on daily water budget approach for all identified crops in each of 10 irrigation systems using available site specific historical climate data, soil physical properties, crop-specific water use coefficients, average growing time and irrigation application system types.

The historical irrigation water requirements calculated by water budget model can be used to develop irrigation water allocation and management practices for Hawaii's agricultural industry in order to optimize irrigation water use efficiency, minimize the potential for non-point source pollution of groundwater, and reduce costs associated with resource loss by leaching. Planning for Hawaii's future water demands requires the ability to synthesize thousands of permitted consumptive uses as well as the ability to consider modifications to existing permits in response to future land-use scenarios. Such regional planning requires a methodology that can rapidly analyze all irrigated crops within a region and account for soils and climate variability.

To calculate the irrigation component of the water budget equation, historical daily rainfall and $ET_O$ data were obtained for at least one location per system for each of the ten systems, with the exception of Kauai Coffee and Kekaha, both having two climate and soil data sets resulting in 12 separate system calculations. The climate stations and characteristics of 10 target systems are given in Appendix 9.4. During this study the $ET_O$ was calculated using daily pan evaporation measurements or estimated from minimum and maximum temperature measurements and $Q_R$ was calculated using SCS curve number method and daily rainfall data. $ET_C$ was calculated by multiplying $K_C$ with $ET_O$ assuming no soil water stress occurs on crops during growth period with the help of irrigation water. The $Q_D$ values were calculated internally during daily water budget calculations as any amount of water exceeding field capacity after soil water redistribution process ends. The only unknown in the water budget approach, the *IRR*, was calculated for each day of the historical climate data period. The calculated average *IRR* values represent the ideal irrigation requirement for an optimal crop yield for given climate conditions because no soil water stress is assumed to occur during crop growth. Irrigations are scheduled based on an allowable level (depth or volume) of soil water depletion from the crop root zone. Irrigation amounts are calculated to restore the soil water content to field capacity.

Statistical analysis was performed on the calculated long term historical irrigation requirements data set. Average, maximum and minimum *IRR* values, median, and coefficient of variation were calculated for each Julian day. Then, these daily values were summed along a given crop growth season to obtain seasonal or annual *IRR* values.

### 3.3 Irrigation Requirements

Irrigation requirement for different crop types in the different irrigation systems were calculated based on the daily water budget approach that uses long-term daily weather inputs (rainfall, potential evapotranspiration), groundwater contribution (if any), drainage, runoff, soil physical properties and crop parameters. Irrigation water demand for annual crops was calculated for two cropping season a year, one in the summer and one in the winter to represent the high and low irrigation requirements during the course of a year, respectively. However, irrigation water demands for perennial crops were calculated for a complete year. Irrigation requirements calculated for each crop represent the historical “seasonal average” irrigation requirement without any soil water stress on crop yield.

#### 3.3.1 Water Budget Approach

The daily water budget is formulated as water input minus water output equals to change in the water storage in the root zone. Water inputs are rainfall ($P$), net irrigation requirements ($IRR_{net}$) and groundwater contribution ($G$), which is zero in all ten systems because of deep water table. Water outputs are $Q_R$, $ET_C$ , and $Q_D$.

The daily water balance equation for the soil column defined by the crop root zone expressed in terms of equivalent water depth per unit area (in) is:

$$\Delta S = P + G + IRR_{net} - (Q_D + Q_R + ET_c) \tag{1}$$

where $\Delta S$ is the change in soil water storage expressed as equivalent water depth (in). The water storage capacity ($S$) is amount of water that is available for plant uptake. It is calculated as the equivalent water between field capacity and permanent wilting point for a given soil multiplied by the depth of the root zone.

Irrigations were assumed to start when the available water for plant uptake decreased to a predetermined minimum allowable level, which is termed as allowable soil water depletion (AWD) percentage. The AWD values were determined from the literature and are fractions of the available soil water storage capacity in the crop root zone which can be allowed to be depleted without significant reduction of crop yield. The AWD values for the annual crops used in this study are given in Table 3.1. An AWD value of 0.50 was used for all perennial crops listed in Appendix 9.5. A value of 0.50 means that 50% of the available water in the irrigated crop root zone is allowed to be depleted between two consecutive irrigation events.

Irrigation is intended to replenish the water content in the root zone to reach field capacity. The gross irrigation requirement (*IRR*) was calculated for each crop using the following equation, which is derived from Equation 1:

$$IRR = \frac{\Delta S + ET_c - (P - Q_R - Q_D)}{f_i} \quad (2)$$

where $f_i$ is the irrigation efficiency.

The values of $ET_C$ used in Equation 2 were calculated using long term historical daily $ET_O$ values, which were calculated using historical pan evaporation data or 1985 Hargreaves equation (Hargreaves and Samani, 1985). The Hargreaves equation uses historical daily maximum and minimum temperatures. Equation 3 was used to calculate $ET_C$ as:

$$ET_C = K_C * ET_O \quad (3)$$

The values of $K_C$ used for annual and perennial crops are listed in Table 3.1 and Appendix 9.5, respectively. Average lengths of annual crop growth stages are given in Table 3.1 as fractions of the crop growing season. For example, stages 1-4 for cantaloupe would be expected to have durations of 8, 50, 21 and 21% of the growing season, respectively. Crop growth stages represent periods of development with different leaf area indices (LAI), and subsequently different water use. Perennial crops differ from annuals in that $K_C$ values are primarily determined by annual reproductive cycles and are calculated monthly. It was for this reason that perennial crops whose lifecycle more closely reflects the dynamic LAI characteristics and/or relative seasonal independence of annual crops (e.g. pineapple, banana, sugarcane, and banagrass) were categorized as perennials for this work.

**3.3.2 Historical Climate Data**

Historical long-term daily rainfall data were obtained for stations within each system from the National Climate Data Center (NCDC) on-line database at http://www.ncdc.noaa.gov/oa/climate/climateinventories.html, with an exception being Kunia substation rainfall data (Waiahole system) that was obtained from the Hawaii Agricultural Research Center (HARC). The data set of HARC or of Ekhern and Chang (1985) were used in preference to the online database because it was accompanied with simultaneous measurements of daily pan-evaporation (*PE*). Potential evapotranspiration was determined from historical *PE* data for all systems, except Waimanalo and Upcountry Maui, as:

$$ET_O = PE * K_P \quad (4)$$

where $K_P$ is a pan coefficient. In the tropics, actual $K_P$ values ranges between 0.60 and 1.1 depending on season and location, with a mean value close to 0.80 across these variables (Harmsen et al., 2003; Pereira et al, 1995; Sumner and Jacobs, 2005). Because extensive climate data was not available to adjust $K_P$ to site specific conditions, a $K_P$ value of 0.8 was used across systems. Reliable pan evaporation data was unavailable for the Waimanalo and Upcountry systems. However, long term historical daily temperature data were available for these systems and were used to calculate $ET_O$ using the 1985 Hargreaves equation (Appendix 3-A).

Table 3.1. Annual crop effective root depth, Kc values and stage lengths as a fraction of growing period

| Crop | Root depth (in) | | $Kc_{initial}$ | $Kc_{mid}$ | $Kc_{late}$ | Duration (fraction of crop cycle) | | | | Allowable water depletion (fraction of total) | | | | Irrigation type | Irrigation efficiency (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial | Final | | | | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 1 | Stage 2 | Stage 3 | Stage 4 | | |
| Alfalfa, initial | 8 | 24 | 0.4 | 0.95 | 0.9 | 0.14 | 0.38 | 0.31 | 0.17 | 0.5 | 0.5 | 0.5 | 0.5 | Sprinkler | 70 |
| Alfalfa, ratoon | 24 | 24 | 0.4 | 0.95 | 0.9 | 0.14 | 0.38 | 0.31 | 0.17 | 0.5 | 0.5 | 0.5 | 0.5 | Sprinkler | 70 |
| Bana Grass (Sudan), 1st cut | 18 | 36 | 0.5 | 0.9 | 0.85 | 0.33 | 0.33 | 0.2 | 0.14 | 0.5 | 0.5 | 0.5 | 0.5 | Sprinkler | 70 |
| Bana Grass (Sudan), 2nd cut | 36 | 36 | 0.5 | 1.15 | 1.1 | 0.08 | 0.4 | 0.32 | 0.19 | 0.5 | 0.5 | 0.5 | 0.5 | Sprinkler | 70 |
| Banana, initial | 24 | 48 | 0.5 | 1.1 | 1 | 0.31 | 0.23 | 0.31 | 0.15 | 0.35 | 0.35 | 0.35 | 0.35 | Micro-spray | 80 |
| Banana, ratoon | 48 | 48 | 1 | 1.05 | 1.05 | 0.33 | 0.16 | 0.49 | 0.01 | 0.35 | 0.35 | 0.35 | 0.35 | Micro-spray | 80 |
| Cabbage | 8 | 12 | 0.7 | 1.05 | 0.95 | 0.24 | 0.36 | 0.3 | 0.09 | 0.45 | 0.45 | 0.45 | 0.45 | Drip | 85 |
| Cantaloupe | 8 | 12 | 0.5 | 0.85 | 0.6 | 0.08 | 0.5 | 0.21 | 0.21 | 0.35 | 0.35 | 0.35 | 0.35 | Drip | 85 |
| Dry Onion | 8 | 12 | 0.7 | 1.05 | 0.75 | 0.1 | 0.17 | 0.5 | 0.23 | 0.25 | 0.25 | 0.25 | 0.9 | Drip | 85 |
| Eggplant | 8 | 12 | 0.7 | 1.05 | 0.9 | 0.21 | 0.32 | 0.29 | 0.18 | 0.4 | 0.4 | 0.4 | 0.4 | Drip | 85 |
| Ginger (AWD potatoes) | 8 | 12 | 0.7 | 1.05 | 0.75 | 0.1 | 0.17 | 0.5 | 0.23 | 0.25 | 0.25 | 0.25 | 0.25 | Drip | 85 |
| Lettuce | 8 | 12 | 0.7 | 1 | 0.95 | 0.2.7 | 0.4 | 0.2 | 0.13 | 0.3 | 0.3 | 0.3 | 0.3 | Sprinkler | 70 |
| Other melon | 8 | 12 | 0.5 | 1.05 | 0.75 | 0.21 | 0.29 | 0.33 | 0.17 | 0.35 | 0.35 | 0.35 | 0.35 | Drip | 85 |
| Pineapple, year 1 | 12 | 12 | 0.5 | 0.3 | 0.3 | 0.16 | 0.33 | 0.26 | 0.25 | 0.6 | 0.6 | 0.6 | 0.6 | Drip | 85 |
| Pineapple, year 2 | 24 | 24 | 0.3 | 0.3 | 0.3 | 0.38 | 0.32 | 0.27 | 0.03 | 0.6 | 0.6 | 0.6 | 0.6 | Drip | 85 |
| Pumpkin | 8 | 12 | 0.5 | 1 | 0.8 | 0.2 | 0.3 | 0.3 | 0.2 | 0.35 | 0.35 | 0.35 | 0.5 | Drip | 85 |
| Seed Corn | 12 | 18 | 0.4 | 1.2 | 0.5 | 0.16 | 0.28 | 0.32 | 0.24 | 0.6 | 0.6 | 0.6 | 0.8 | Drip | 85 |
| Sugarcane, New-year 1 | 18 | 36 | 0.4 | 1.25 | 1.25 | 0.21 | 0.29 | 0.25 | 0.25 | 0.65 | 0.65 | 0.65 | 0.65 | Drip | 85 |
| Sugarcane, New- year 2 | 36 | 36 | 1.25 | 1.25 | 0.75 | 0.14 | 0.14 | 0.14 | 0.59 | 0.65 | 0.65 | 0.65 | 0.65 | Drip | 85 |
| Sugarcane, ratoon | 36 | 36 | 0.4 | 1.25 | 0.75 | 0.1 | 0.15 | 0.46 | 0.29 | 0.65 | 0.65 | 0.65 | 0.65 | Drip | 85 |
| Sweet potato | 8 | 12 | 0.5 | 1.15 | 0.65 | 0.12 | 0.24 | 0.4 | 0.24 | 0.65 | 0.65 | 0.65 | 0.65 | Drip | 85 |
| Taro | 8 | 12 | 1.05 | 1.15 | 1.1 | 0.2 | 0.13 | 0.4 | 0.27 | 0 | 0 | 0 | 0 | Flood | 50 |
| Tomato | 8 | 12 | 0.6 | 1.15 | 0.8 | 0.2 | 0.27 | 0.34 | 0.19 | 0.4 | 0.4 | 0.4 | 0.65 | Drip | 85 |
| Watermelon | 8 | 12 | 0.4 | 1 | 0.75 | 0.15 | 0.26 | 0.26 | 0.32 | 0.26 | 0.32 | 0.26 | 0.32 | Drip | 85 |

Station locations and climatic information are also presented Figures 3.B-1 to 3.B-4 in Appendix 3-B. Historical annual rainfall is the lowest in the Waimea, Waiahole, Upcountry and Kekaha systems (17, 21, 24, and 25 inches, respectively) and highest in the Lower Hamakua and East Kauai systems (95 and 74 inches, respectively). The $ET_O$ is comparatively less variable (ranging 47 to 94 inches), among systems, than rainfall (ranging 17 to 94 inches) annually, and is generally inversely related to rainfall. Deficits between annual rainfall and $ET_O$ were greatest in the West Maui and Molokai systems, averaging about 58 inches less rainfall than $ET_O$. The Lower Hamakua and East Kauai systems have clear water excess as they receive more annual rainfall than water losses through $ET_O$ (31 and 18 inches more, respectively).

Orthographic lifting and subsequent cooling of the moisture laden tradewinds are the primary rainfall-producing mechanism over the islands. This results in substantially less rain on the leeward side due to a rain shadow effect. As a result, water deficits relative to $ET_O$ are greater on the leeward, relative to the windward, sides of the Islands. At a single location, there is significant temporal rainfall variability from month to month. In most of the systems, rainfall maxima and minima occur in January and June, respectively. The difference between winter maxima and summer minima are greatest in dry areas, while wet areas are characterized by three peaks in precipitation throughout the year, including a rainfall spike during the summer months. Spatial variability in rainfall occurs not just across mountain ranges and between islands, but also within individual watersheds and is primarily influenced by topography. In the Kauai Coffee system, a gradient of approximately 400 feet in the Mauka-Makai direction results in a difference of 24 inches of rainfall between the upper and lower portions of the system.

### 3.3.3 Soil

Representative soil series, textures, and water-holding capacities, soil thicknesses, and water table depths for each system were identified with the USDA Soil Survey of the State of Hawaii and supporting documents (USDA, 1972; USDA, 1979). The water storage capacity within in the crop root zone was defined as the product of the soil water-holding capacity of the soil (Table 3.2), and the depth of the effective root zone for annual (Table 3.1) and perennial (Appendix 9.5) crops.

Table 3.2. Representative Soils for Each of the Ten Target Systems

| System | Station | Soil series | Texture | Water holding capacity (in/in) |
|---|---|---|---|---|
| East Kauai | Lihue Variety | Kapaa | Silty clay | 0.14 |
| Kauai Coffee | Wahiawa | Makaweli | Stony silty clay loam | 0.15 |
| Kauai Coffee | Brydswood | Koloa | Stony silty clay | 0.11 |
| Kekaha | Kekaha | Kekaha | Silty clay | 0.105 |
| Kekaha | Mana | Lualualei | Clay | 0.115 |
| Waiahole | Kunia.Sub | Kunia | Silty clay | 0.13 |
| Waimanalo | Wai.Exp.Sta | Waialua | Silty clay | 0.14 |
| Molokai | Kaunakakai | Molokai | Silty clay loam | 0.12 |
| West Maui | Pohakea | Pelehu / Jaucas | Clay loam / Sand | 0.13 / 0.04-0.05 |
| Upcountry | Kula | Kula | Loam | 0.14 |
| Waimea | Lalaumilo | Waimea | V. fine sandy loam | 0.14 at 0-50 in<br>0.02 at 50-90in |
| Lower Hamakua | Paauilo | Paauhau | Silty clay loam | 0.14 at 0-50 in<br>0.06 at 50-90 in |

Available soil water capacity is defined as the difference between field capacity and the permanent wilting point (PWP). Field capacity is defined as the volumetric water content retained in the soil at a soil water potential of -10 centibars (cb). PWP is the soil water potential beyond which a crop cannot extract water, and dies. PWP is defined as the volumetric water content retained in the soil at a water potential of -15 bars (Smajstrla, 1990). Table 3.2 shows the representative water holding capacity values of the major soil series. However, the model considered all soil series within the service areas.

### 3.3.4 Irrigation System Types

Drip and micro-sprinkler were the irrigation system types selected for most crops, with the former assigned primarily to vegetable crops and the latter to fruits and other perennials. Other system types assigned were: multiple sprinklers (alfalfa and lettuce), sprinkler – large guns (bana grass) and flood (taro). System efficiency was assumed to be 85, 80, 75, 70, 50, and 20 % for drip, micro-sprinkler, multiple sprinkler, sprinkler-large guns, flood, and nursery container irrigation systems, respectively (Appendix 9.5).

Irrigation requirements for potted dendrobium and dracaena was carried out by assuming the potting media was bark or rock based for dendrobiums and peat based for dracaena, and available water holding capacity was 0.05 and 0.20 for the dendrobium and dracaena media respectively. Calculations were then made for each system using the same historical climate data used for the other commodities. Micro spray and nursery container irrigation systems were employed for both commodities in all systems.

### 3.3.5 Irrigation Losses

An important issue that needs consideration is the water loss that occurs during irrigation due to irrigation system efficiency. These losses are added into irrigation requirements by dividing IRR with a coefficient of irrigation system efficiency ($f_i$), which is less than one. However, water losses due to conveyance losses were not included in the calculations. In all water supply systems, some proportion of the water diverted from rivers or dams is lost in conveyance to irrigation delivery systems. The efficiency of irrigation delivery is measured as the volume of water recorded at irrigator meters divided by the volume diverted from the irrigation district intake. This definition encompasses losses due to outfalls or water flowing from the downstream end of a delivery system, farm irrigation water meter inaccuracy, unrecorded usage, leakage, seepage of water through the beds of irrigation channels, and evaporation losses occur in channels and storages.

The benefits and costs of improving irrigation conveyance efficiency are highly site and situation specific; there is no single solution to increase conveyance efficiency. Losses from outfalls can be reduced by improving water control in channels through the use of channel control technology and/or changing management practices. Losses through meter inaccuracy can be reduced by fitting more-accurate meters or by rehabilitating existing meters. Leakage or seepage in open channels can be reduced by channel sealing, lining of earth channels, or pipelining. The pipelining of open-channel irrigation often reduces seepage and evaporation losses. Pipelining is economically feasible where there is a need for on-demand, pressurized water supplies for sprinkler and drip irrigation. Evaporation losses in storages can be reduced through modification of storages or weirs to raise water levels and/or reduce the surface area of the storage or weir pool.

Conveyance losses in the US vary from 30% to 50% with the average of 41% (Bos and Nugteren, 1990). Therefore, losses depend on the type and quality of conveyance properties of on farm site specific irrigation systems, a conveyance efficiency factor can be considered to incorporate conveyance losses. In pressurized closed conduits, conveyance efficiency may be nearly 100%, but in open surface irrigation channels and ditches, conveyance efficiencies may be quite low.

### 3.3.6 Surface Runoff

Surface runoff ($Q_R$), used in Equation 2, was calculated using SCS curve number method using the following equation:

$$Q_R = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{5}$$

where $P$ is daily rainfall (in), $S$ is potential maximum retention which is related to curve number as:

$$S = \frac{1000}{CN} - 10 \tag{6}$$

$CN$ is the curve number which is related to the imperviousness of the surface. For impervious and water surfaces $CN$=100, for natural surfaces $CN$ is less than 100. Hydrologic soil groups and land use type are used to determine $CN$. The hydrological soil groups of all the systems are in group C. For land use of cultivated land, and hydrologic soil group of C, a $CN$ value of 78 was chosen. After calculating runoff, net rainfall is calculated by subtracting it from the measured rainfall values.

### 3.3.7 Irrigation Requirement Calculation Procedure

The following procedure was followed to calculate *IRR* and other water budget components for each crop type for each irrigation system:

1- Long term historical daily rainfall and $ET_O$ values were obtained for each station. $ET_O$ was estimated from pan evaporation records or the 1985 Hargreaves equation using daily maximum and minimum temperature records.

2- Daily surface runoff was calculated by SCS curve number method with historical daily rainfall data

3- Net rainfall ($P_{\text{net}}$) was calculated by subtracting runoff from measured rainfall. $P_{\text{net}}$ is the portion of rainfall infiltrates to ground surface for crop use.

4- $\text{ET}_\text{C}$ was calculated by multiplying $K_C$ with $ET_O$. The value of $K_C$ changes with growing stage of crop.

5- Historical daily *IRR* were calculated using water budget approach.

6- Statistical analysis was performed on the calculated *IRR* data set. Mean, maximum and minimum values, median, and coefficient of variation of the *IRR* were calculated. Finally these daily values were summed along the growth season of each crop to obtain weekly, monthly, seasonal, or annual *IRR* values.

7- Along the *IRR* values and its statistics for each crop, other water budget components (i.e., net rainfall, runoff, drainage, and crop *ET*) are also calculated for each crop in each system.

8- The calculated *IRR* data set was fitted to Type I Extreme Value Distribution for positive non-zero irrigation values using the least square curve fitting method to determine the *IRR* values having non-exceedance probabilities of 50%, 80%, and 90%, which correspond to the average climate year, 1 in 5, and 1 in 10 year drought conditions, respectively. These probabilities of occurrences of *IRR* are not presented in this report whereas only the mean, maximum and minimum *IRR* values are presented.

## 3.4 Results and Discussion

The calculations on irrigation requirements for various crops using different irrigations systems are believed to be accurate and reliable. The calculations were made for comparing irrigation systems efficiencies and illustrating irrigation requirements for crops. The values may change with location, weather conditions and the prevailing situations in various parts of Hawaii. Therefore, these values should not be taken as recommendations in any case.

Seasonal average *IRR* values for each crop type in each system are tabulated in Table 3.3. Minimum, maximum, and average IRR values for each crop together with net rainfall, runoff, drainage, and crop ET are tabulated for each system in Tables 3.4 and 3.5 (demonstratively shown for windward areas (i.e., Waimanalo) and leeward areas (i.e., Wahiahole), respectively), and in Appendices 9.6 to 9.15.

Temporal and spatial rainfall and planting periods are important components that affect irrigation requirements. Rainfall varies temporally and spatially throughout the islands of Hawaii which results in varied *IRR* demands for the irrigation systems even within the same island. Hydrographically, the islands can be characterized into windward and leeward sides with the windward receiving significantly more rainfall compared to the leeward side. As a result, windward needs less *IRR* compared to leeward. Windward areas such as Waimanalo, East Kauai, and Lower Hamakua, require less irrigation for their crops, due to their higher rainfall, compared to leeward areas such as Molokai, West Maui and Wahiahole. Planting periods or growing seasons also affect *IRR* values; such that crops grown during wet season (October to February) require less water and those grown during dry season (April to August) require more *IRR* (Tables 3.4, 3.5 and Appendices 9.6 to 9.15).

The *IRR* values are generally the highest for all crops where the historical annual rainfalls are the lowest such as the Waimea, Waiahole, Upcountry and Kekaha systems where average annual rainfall values are 17, 21, 24, and 25 inches, respectively. The *IRR* values are the lowest for all crops where the rainfall is highest such as the East Kauai and Lower Hamakua systems where average annual rainfall values are 95 and 74 inches, respectively. Variability among systems was less in $ET_O$ data (48-94 inches) as compared with rainfall data (17-94 inches) annually. Deficits between annual rainfall and potential *ET* were greatest in the West Maui and Molokai systems, averaging about 58 inches less rainfall than potential *ET*. The Lower Hamakua and East Kauai systems have clear water excess as they receive more annual rainfall than water losses through *ET* (31 and 15 inches more, respectively).

Variation in irrigation water requirement can vary not only within systems, but also with crops AND within systems. The *IRR* calculations show some crops needs less water such as pineapples than others, and some crops such as taro, need more water than any other crops within a single irrigation system.

Variations in *IRR* for each system can vary with their location, planting periods and crop types. Multiple annual crops can be grown within a span of one year in the same location by determining which of the crop needs less water and which needs more. The crop requiring more water should be grown during the wet season to reduce the amount of water usage while the crop with lesser *IRR* can be grown during the dry season. Therefore, if a water thirsty crop is planted in wet season and the one with less water requirement is planted in the following dry season, a considerable overall cost reduction in *IRR* can be achieved.

Irrigation requirement for energy crops are presented separately in Table 3.B.1 in Appendix 3-B. Energy crops are corn, sugarcane, banagrass, and leucaena. Sudan grass and eucalyptus were used to calculate *IRR* requirements for Banagrass and leucaena, respectively. All energy crops are annual crops with the exception of Leucaena.

Table 3.3. System Irrigation Requirements by Crop and Season (units are in thousand gallons per acre)

| Crop Type | Irrigation Season | Length (day) | Kekaha (South) | Kekaha IS (North) | Kauai Coffee IS (Lower) | Kauai Coffee IS (upper) | East Kauai IS | Waiahole IS | Waima-nalo IS | Molokai IS | West Maui IS | Up Country IS | Waimea IS | Lower Hamakua IS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alfalfa, initial | 11-15 TO 1-15 | 62 | 57 | 52 | 33 | 14 | 5 | 62 | 5 | 125 | 95 | 30 | 38 | 8 |
| Alfalfa, initial | 5-15 TO 7-15 | 62 | 209 | 225 | 182 | 87 | 24 | 217 | 100 | 375 | 345 | 147 | 147 | 122 |
| Alfalfa, ratoon | 11-15 TO 1-15 | 62 | 52 | 49 | 27 | 11 | 5 | 52 | 5 | 111 | 187 | 27 | 38 | 5 |
| Alfalfa, ratoon | 5-15 TO 7-15 | 62 | 231 | 215 | 179 | 81 | 22 | 217 | 95 | 369 | 353 | 152 | 163 | 117 |
| Banana, initial | 10- 1 TO 9-30 | 365 | 1225 | 1010 | 869 | 475 | 130 | 986 | 413 | 1705 | 1556 | 660 | 940 | 394 |
| Banana, initial | 5- 1 TO 4-30 | 365 | 771 | 771 | 668 | 244 | 54 | 755 | 209 | 1447 | 1274 | 489 | 771 | 204 |
| Banana, ratoon | 10- 1 TO 9-30 | 365 | 969 | 967 | 828 | 437 | 114 | 929 | 402 | 1632 | 1496 | 630 | 910 | 364 |
| Banana, ratoon | 5- 1 TO 4-30 | 365 | 595 | 728 | 635 | 217 | 46 | 711 | 190 | 1350 | 1203 | 462 | 747 | 177 |
| Cabbage | 11- 1 TO 1-31 | 92 | 103 | 106 | 81 | 43 | 22 | 95 | 22 | 212 | 160 | 65 | 90 | 41 |
| Cabbage | 5- 1 TO 7-31 | 92 | 369 | 353 | 291 | 166 | 60 | 334 | 166 | 557 | 538 | 242 | 247 | 177 |
| Cantaloupe | 10-15 TO 2-15 | 124 | 130 | 133 | 103 | 52 | 24 | 128 | 27 | 253 | 209 | 84 | 114 | 49 |
| Cantaloupe | 4-15 TO 8-15 | 123 | 421 | 402 | 323 | 166 | 54 | 386 | 182 | 614 | 611 | 277 | 285 | 171 |
| Dry Onion | 10-15 TO 2-15 | 124 | 187 | 190 | 160 | 81 | 43 | 185 | 46 | 358 | 301 | 122 | 166 | 73 |
| Dry Onion | 4-15 TO 8-15 | 123 | 554 | 532 | 456 | 269 | 109 | 527 | 277 | 804 | 793 | 388 | 396 | 266 |
| Eggplant | 10-15 TO 2-15 | 124 | 166 | 166 | 141 | 73 | 38 | 157 | 41 | 320 | 258 | 106 | 147 | 65 |
| Eggplant | 4-15 TO 8-15 | 123 | 511 | 491 | 415 | 236 | 90 | 481 | 244 | 741 | 747 | 350 | 358 | 234 |
| Ginger (AWD Potatoes) | 10- 1 TO 9-30 | 365 | 1271 | 1241 | 1075 | 603 | 274 | 1217 | 597 | 1814 | 1776 | 904 | 1005 | 530 |
| Ginger (AWD Potatoes) | 5- 1 TO 4-30 | 365 | 1217 | 1173 | 1048 | 568 | 223 | 1184 | 530 | 1838 | 1760 | 850 | 1005 | 524 |
| Lettuce | 11-15 TO 1-15 | 62 | 87 | 92 | 71 | 41 | 24 | 92 | 22 | 171 | 136 | 62 | 73 | 38 |
| Lettuce | 5-15 TO 7-15 | 62 | 272 | 258 | 215 | 122 | 49 | 261 | 130 | 421 | 399 | 187 | 185 | 155 |
| Other Melon | 10-15 TO 2-15 | 124 | 166 | 168 | 141 | 73 | 41 | 163 | 41 | 323 | 261 | 111 | 144 | 68 |
| Other Melon | 4-15 TO 8-15 | 123 | 511 | 494 | 410 | 234 | 90 | 478 | 242 | 741 | 744 | 348 | 356 | 234 |
| Pineapple, year 1 | 10- 1 TO 9-30 | 365 | 258 | 231 | 128 | 16 | 0 | 212 | 22 | 443 | 415 | 103 | 166 | 24 |
| Pineapple, year 1 | 5- 1 TO 4-30 | 365 | 369 | 334 | 258 | 100 | 14 | 315 | 92 | 692 | 627 | 182 | 247 | 98 |
| Pineapple, year 2 | 10- 1 TO 9-30 | 365 | 280 | 247 | 163 | 33 | 3 | 231 | 33 | 500 | 448 | 111 | 185 | 27 |
| Pineapple, year 2 | 5- 1 TO 4-30 | 365 | 337 | 315 | 258 | 84 | 5 | 315 | 87 | 665 | 600 | 185 | 253 | 76 |
| Pumpkin | 10-15 TO 2-15 | 124 | 157 | 157 | 130 | 68 | 35 | 152 | 38 | 307 | 247 | 16 | 136 | 60 |
| Pumpkin | 4-15 TO 8-15 | 123 | 491 | 472 | 394 | 220 | 79 | 459 | 228 | 706 | 717 | 331 | 342 | 217 |
| Seed, Corn | 10-15 TO 2-15 | 124 | 141 | 149 | 122 | 49 | 27 | 144 | 24 | 318 | 250 | 84 | 128 | 43 |
| Seed, Corn | 4-15 TO 8-15 | 123 | 505 | 497 | 432 | 258 | 95 | 475 | 236 | 790 | 755 | 342 | 364 | 247 |
| Sugarcane, New-year 1 | 10- 1 TO 9-30 | 365 | 1317 | 1260 | 1157 | 709 | 274 | 1225 | 592 | 2050 | 1857 | 874 | 1089 | 519 |
| Sugarcane, New-year 1 | 5- 1 TO 4-30 | 365 | 1021 | 997 | 912 | 353 | 98 | 983 | 323 | 1765 | 1559 | 673 | 921 | 282 |
| Sugarcane, New- | 10- 1 TO 9-30 | 365 | 1121 | 1073 | 964 | 494 | 149 | 1043 | 429 | 1784 | 1605 | 714 | 934 | 310 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| year 2 | | | | | | | | | | | | | | |
| Sugarcane, New-year 2 | 5- 1 TO 4-30 | 365 | 1056 | 1026 | 942 | 451 | 103 | 1029 | 386 | 1773 | 1632 | 717 | 967 | 372 |
| Sugarcane, ratoon | 10- 1 TO 9-30 | 365 | 1301 | 1255 | 1159 | 646 | 244 | 1214 | 538 | 2080 | 1857 | 858 | 1092 | 434 |
| Sugarcane, ratoon | 5- 1 TO 4-30 | 365 | 1208 | 1181 | 1108 | 557 | 147 | 1187 | 467 | 2028 | 1836 | 831 | 1105 | 448 |
| Sweet potatoes | 10- 1 TO 2-28 | 151 | 255 | 255 | 225 | 103 | 49 | 255 | 62 | 478 | 399 | 166 | 236 | 90 |
| Sweet potatoes | 4- 1 TO 8-31 | 153 | 711 | 690 | 619 | 375 | 152 | 654 | 269 | 1029 | 1018 | 513 | 535 | 342 |
| Taro | 10- 1 TO 9-30 | 365 | 3253 | 3259 | 3340 | 2680 | 2053 | 3231 | 2172 | 4969 | 4372 | 2675 | 2770 | 2631 |
| Taro | 5- 1 TO 4-30 | 365 | 3201 | 3231 | 3286 | 2637 | 2018 | 3231 | 2134 | 4915 | 4318 | 2637 | 2743 | 2591 |
| Tomato | 10-15 TO 2-15 | 124 | 185 | 182 | 157 | 81 | 43 | 174 | 46 | 356 | 288 | 117 | 160 | 71 |
| Tomato | 4-15 TO 8-15 | 123 | 554 | 535 | 462 | 274 | 114 | 524 | 277 | 796 | 804 | 386 | 396 | 272 |
| Watermelon | 10-15 TO 2-15 | 124 | 166 | 171 | 138 | 71 | 35 | 166 | 41 | 318 | 263 | 109 | 144 | 65 |
| Watermelon | 4-15 TO 8-15 | 123 | 500 | 483 | 399 | 220 | 84 | 470 | 234 | 720 | 720 | 342 | 350 | 228 |
| Coffee | 1- 1 TO 12-31 | 365 | 1312 | 1274 | 1149 | 559 | 155 | 1282 | 551 | 2042 | 1914 | 915 | 1121 | 434 |
| Dendrobium, pot, micro-sprink | 1- 1 TO 12-31 | 365 | 1646 | 1632 | 1551 | 997 | 616 | 1627 | 899 | 2463 | 2281 | 1293 | 1407 | 972 |
| Dendrobium, pot, nursery spray | 1- 1 TO 12-31 | 365 | 5081 | 5132 | 5377 | 4290 | 3259 | 5024 | 3557 | 7902 | 6843 | 4155 | 4426 | 4046 |
| Draceana, pot, micro-sprink | 1- 1 TO 12-31 | 365 | 1643 | 1624 | 1534 | 986 | 557 | 1618 | 923 | 2447 | 2257 | 1274 | 1390 | 961 |
| Draceana, pot, nursery spray | 1- 1 TO 12-31 | 365 | 5051 | 5078 | 5349 | 4209 | 3123 | 4996 | 3476 | 7875 | 6816 | 4100 | 4399 | 3910 |
| Eucaluptus closed canopy | 1- 1 TO 12-31 | 365 | 1464 | 1431 | 1325 | 657 | 187 | 1409 | 611 | 2292 | 2123 | 1040 | 1284 | 491 |
| Eucalyptus young | 1- 1 TO 12-31 | 365 | 714 | 676 | 524 | 141 | 5 | 676 | 179 | 1113 | 1108 | 434 | 619 | 136 |
| Guava | 1- 1 TO 12-31 | 365 | 1268 | 1227 | 1100 | 489 | 109 | 1238 | 486 | 1974 | 1855 | 874 | 1102 | 361 |
| Heliconia | 1- 1 TO 12-31 | 365 | 1455 | 1420 | 1301 | 657 | 198 | 1423 | 633 | 2267 | 2104 | 1032 | 1252 | 500 |
| Kikuyu Grass | 1- 1 TO 12-31 | 365 | 1564 | 1523 | 1398 | 706 | 212 | 1534 | 679 | 2428 | 2259 | 1113 | 1339 | 570 |
| Lychee | 1- 1 TO 12-31 | 365 | 1195 | 1233 | 1105 | 491 | 119 | 1233 | 486 | 1982 | 1855 | 877 | 1097 | 356 |
| Macadamia nut | 1- 1 TO 12-31 | 365 | 1217 | 1255 | 1127 | 519 | 128 | 1265 | 508 | 2026 | 1901 | 899 | 1124 | 399 |
| Ti | 1- 1 TO 12-31 | 365 | 1369 | 1417 | 1298 | 657 | 201 | 1423 | 633 | 2267 | 2104 | 1032 | 1252 | 500 |

Table 3.4. Waimanalo (Waimanalo Experiment Station) Seasonal Irrigation Requirements for Selected Crops

| **Crop Type** | **Irrigation Season** | **Length** (day) | **Net Rainfall** (inch) | **Potential ET** (inch) | **Crop ET** (inch) | **Drainage** (inch) | **Runoff** (inch) | **Mean Irrigation Requirement** (inch) | **Maximum Irrigation Requirement** (inch) | **Minimum Irrigation Requirement** (inch) | **Mean Irrigation Requirement** (1000 gallons/acre) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alfalfa, initial | 11-15 TO 1-15 | 62 | 9.7 | 5.9 | 5.1 | 5.1 | 2.4 | 0.2 | 2.3 | 0.0 | 5 |
| Alfalfa, initial | 5-15 TO 7-15 | 62 | 3.3 | 9.5 | 7.7 | 0.5 | 0.3 | 3.7 | 6.1 | 0.0 | 100 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alfalfa, ratoon | 11-15 TO 1-15 | 62 | 9.7 | 5.9 | 5.1 | 4.7 | 2.4 | 0.2 | 2.3 | 0.0 | 5 |
| Alfalfa, ratoon | 5-15 TO 7-15 | 62 | 3.3 | 9.5 | 7.7 | 0.3 | 0.3 | 3.5 | 6.9 | 0.0 | 95 |
| Banana, initial | 10- 1 TO 9-30 | 365 | 35.6 | 47.4 | 43.6 | 11.8 | 7.1 | 15.2 | 23.3 | 7.5 | 413 |
| Banana, initial | 5- 1 TO 4-30 | 365 | 35.6 | 47.5 | 39.1 | 5.9 | 7.1 | 7.7 | 19.5 | 0.8 | 209 |
| Banana, ratoon | 10- 1 TO 9-30 | 365 | 35.6 | 47.4 | 42.9 | 11.0 | 7.1 | 14.8 | 23.1 | 6.1 | 402 |
| Banana, ratoon | 5- 1 TO 4-30 | 365 | 35.6 | 47.5 | 38.5 | 5.3 | 7.1 | 7.0 | 18.3 | 0.0 | 190 |
| Cabbage | 11- 1 TO 1-31 | 92 | 14.2 | 9.1 | 8.0 | 7.2 | 3.8 | 0.8 | 2.3 | 0.0 | 22 |
| Cabbage | 5- 1 TO 7-31 | 92 | 5.4 | 14.0 | 11.8 | 0.9 | 0.7 | 6.1 | 9.4 | 3.0 | 166 |
| Cantaloupe | 10-15 TO 2-15 | 124 | 18.3 | 12.8 | 10.0 | 9.3 | 4.7 | 1.0 | 2.7 | 0.0 | 27 |
| Cantaloupe | 4-15 TO 8-15 | 123 | 7.3 | 18.5 | 13.9 | 1.1 | 0.9 | 6.7 | 10.1 | 3.6 | 182 |
| Dry Onion | 10-15 TO 2-15 | 124 | 18.3 | 12.8 | 12.0 | 8.3 | 4.7 | 1.7 | 4.5 | 0.5 | 46 |
| Dry Onion | 4-15 TO 8-15 | 123 | 7.3 | 18.5 | 17.3 | 1.0 | 0.9 | 10.2 | 14.4 | 5.3 | 277 |
| Eggplant | 10-15 TO 2-15 | 124 | 18.3 | 12.8 | 11.3 | 8.7 | 4.7 | 1.5 | 3.2 | 0.0 | 41 |
| Eggplant | 4-15 TO 8-15 | 123 | 7.3 | 18.5 | 16.0 | 1.1 | 0.9 | 9.0 | 12.9 | 5.3 | 244 |
| Ginger (AWD Potatoes) | 10- 1 TO 9-30 | 365 | 35.6 | 47.4 | 44.9 | 11.6 | 7.1 | 22.0 | 30.7 | 11.2 | 597 |
| Ginger (AWD Potatoes) | 5- 1 TO 4-30 | 365 | 35.6 | 47.5 | 43.6 | 9.8 | 7.1 | 19.5 | 29.8 | 12.1 | 530 |
| Lettuce | 11-15 TO 1-15 | 62 | 9.7 | 5.9 | 5.0 | 5.5 | 2.4 | 0.8 | 2.1 | 0.0 | 22 |
| Lettuce | 5-15 TO 7-15 | 62 | 3.3 | 9.5 | 7.5 | 0.6 | 0.3 | 4.8 | 7.1 | 2.5 | 130 |
| Other Melon | 10-15 TO 2-15 | 124 | 18.3 | 12.8 | 11.2 | 8.7 | 4.7 | 1.5 | 3.4 | 0.2 | 41 |
| Other Melon | 4-15 TO 8-15 | 123 | 7.3 | 18.5 | 16.0 | 1.1 | 0.7 | 8.9 | 12.6 | 5.4 | 242 |
| Pineapple, year 1 | 10- 1 TO 9-30 | 365 | 35.6 | 47.4 | 23.3 | 14.5 | 7.1 | 0.8 | 3.6 | 0.0 | 22 |
| Pineapple, year 1 | 5- 1 TO 4-30 | 365 | 35.6 | 47.5 | 24.3 | 14.5 | 7.1 | 3.4 | 7.8 | 0.0 | 92 |
| Pineapple, year 2 | 10- 1 TO 9-30 | 365 | 35.6 | 47.4 | 24.6 | 13.5 | 7.1 | 1.2 | 4.8 | 0.0 | 33 |
| Pineapple, year 2 | 5- 1 TO 4-30 | 365 | 35.6 | 47.5 | 25.4 | 12.9 | 7.1 | 3.2 | 7.4 | 0.0 | 87 |
| Pumpkin | 10-15 TO 2-15 | 124 | 18.3 | 12.8 | 10.9 | 8.8 | 4.7 | 1.4 | 3.2 | 0.2 | 38 |
| Pumpkin | 4-15 TO 8-15 | 123 | 7.3 | 18.5 | 15.5 | 1.1 | 0.9 | 8.4 | 12.1 | 4.9 | 228 |
| Seed, Corn | 10-15 TO 2-15 | 124 | 18.3 | 12.8 | 12.0 | 7.5 | 4.7 | 0.9 | 4.1 | 0.0 | 24 |
| Seed, Corn | 4-15 TO 8-15 | 123 | 7.3 | 18.5 | 17.2 | 0.9 | 0.9 | 8.7 | 13.0 | 4.1 | 236 |
| Sugarcane, New- year 1 | 10- 1 TO 9-30 | 365 | 35.6 | 47.4 | 50.2 | 10.8 | 7.1 | 21.8 | 32.2 | 12.1 | 592 |
| Sugarcane, New- year 1 | 5- 1 TO 4-30 | 365 | 35.6 | 47.5 | 45.4 | 4.5 | 7.1 | 11.9 | 26.1 | 2.8 | 323 |
| Sugarcane, New- year 2 | 10- 1 TO 9-30 | 365 | 35.6 | 47.4 | 46.2 | 8.2 | 7.1 | 15.8 | 26.0 | 3.9 | 429 |
| Sugarcane, New- year 2 | 5- 1 TO 4-30 | 365 | 35.6 | 47.5 | 45.0 | 4.7 | 7.1 | 14.2 | 27.9 | 7.8 | 386 |
| Sugarcane, ratoon | 10- 1 TO 9-30 | 365 | 35.6 | 47.4 | 50.7 | 7.6 | 7.1 | 19.8 | 32.3 | 8.0 | 538 |
| Sugarcane, ratoon | 5- 1 TO 4-30 | 365 | 35.6 | 47.5 | 49.0 | 3.6 | 7.1 | 17.2 | 32.2 | 9.8 | 467 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sweet potatoes | 10- 1 TO 2-28 | 151 | 20.8 | 16.3 | 15.2 | 8.2 | 5.1 | 2.3 | 5.4 | 0.0 | 62 |
| Sweet potatoes | 4- 1 TO 8-31 | 153 | 8.2 | 18.1 | 17.4 | 1.4 | 1.2 | 9.9 | 14.5 | 5.5 | 269 |
| Taro | 10- 1 TO 9-30 | 365 | 35.6 | 47.4 | 52.6 | 22.7 | 7.1 | 80.0 | 93.1 | 70.4 | 2172 |
| Taro | 5- 1 TO 4-30 | 365 | 35.6 | 47.5 | 52.1 | 22.5 | 7.1 | 78.6 | 90.5 | 68.5 | 2134 |
| Tomato | 10-15 TO 2-15 | 124 | 18.3 | 12.8 | 12.0 | 8.2 | 4.7 | 1.7 | 4.2 | 0.0 | 46 |
| Tomato | 4-15 TO 8-15 | 123 | 7.3 | 18.5 | 17.2 | 1.1 | 0.9 | 10.2 | 14.5 | 6.3 | 277 |
| Watermelon | 10-15 TO 2-15 | 124 | 18.3 | 12.8 | 11.0 | 8.8 | 4.8 | 1.5 | 3.6 | 0.2 | 41 |
| Watermelon | 4-15 TO 8-15 | 123 | 7.3 | 18.5 | 15.7 | 1.1 | 0.9 | 8.6 | 12.6 | 4.8 | 234 |
| Coffee | 1- 1 TO 12-31 | 365 | 35.3 | 47.5 | 44.3 | 7.4 | 7.1 | 20.3 | 33.4 | 9.8 | 551 |
| Dendrobium, pot, micro-sprink | 1- 1 TO 12-31 | 365 | 35.3 | 47.5 | 47.6 | 14.4 | 7.1 | 33.1 | 47.9 | 23.3 | 899 |
| Dendrobium, pot, nursery spray | 1- 1 TO 12-31 | 365 | 35.3 | 47.5 | 47.6 | 20 | 7.1 | 131 | 151 | 109 | 3557 |
| Draceana, pot micro-sprink | 1- 1 TO 12-31 | 365 | 35.3 | 47.5 | 47.6 | 15.1 | 7.1 | 34 | 44 | 23.3 | 923 |
| Draceana, pot, nursery spray | 1- 1 TO 12-31 | 365 | 35.3 | 47.5 | 47.6 | 18.4 | 7.1 | 128 | 150 | 104 | 3476 |
| Eucaluptus closed canopy | 1- 1 TO 12-31 | 365 | 35.3 | 47.5 | 47.6 | 5.9 | 7.1 | 22.5 | 38.4 | 9.6 | 611 |
| Eucalyptus young | 1- 1 TO 12-31 | 365 | 35.3 | 47.5 | 31.8 | 8.9 | 7.1 | 6.6 | 14.9 | 0.0 | 179 |
| Guava | 1- 1 TO 12-31 | 365 | 35.3 | 47.5 | 43.8 | 6.0 | 7.1 | 17.9 | 31.8 | 6.9 | 486 |
| Heliconia | 1- 1 TO 12-31 | 365 | 35.3 | 47.5 | 47.6 | 6.5 | 7.1 | 23.3 | 37.7 | 11.0 | 633 |
| Kikuyu Grass | 1- 1 TO 12-31 | 365 | 35.3 | 47.5 | 47.6 | 6.6 | 7.1 | 25.0 | 39.9 | 11.5 | 679 |
| Lychee | 1- 1 TO 12-31 | 365 | 35.3 | 47.5 | 43.9 | 5.8 | 7.1 | 17.9 | 31.9 | 6.8 | 486 |
| Macadamia nut | 1- 1 TO 12-31 | 365 | 35.3 | 47.5 | 44.3 | 6.1 | 7.1 | 18.7 | 31.5 | 7.9 | 508 |
| Ti | 1- 1 TO 12-31 | 365 | 35.3 | 47.5 | 47.6 | 6.5 | 7.1 | 23.3 | 37.7 | 11.0 | 633 |

Table 3.5. Waiahole (Kunia Substation) Seasonal Irrigation Requirements for Selected Crops

| **Crop Type** | **Irrigation Season** | **Length** (day) | **Net Rainfall** (inch) | **Potential ET** (inch) | **Crop ET** (inch) | **Drainage** (inch) | **Runoff** (inch) | **Mean Irrigation Requirement** (inch) | **Maximum Irrigation Requirement** (inch) | **Minimum Irrigation Requirement** (inch) | **Mean Irrigation Requirement** (1000 gallons/acre) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alfalfa, initial | 11-15 TO 1-15 | 62 | 4.2 | 6.9 | 5.4 | 1.7 | 1.5 | 2.3 | 5.8 | 0.0 | 62 |
| Alfalfa, initial | 5-15 TO 7-15 | 62 | 0.9 | 11.6 | 9.3 | 0.2 | 0.2 | 8.0 | 9.3 | 6.7 | 217 |
| Alfalfa, ratoon | 11-15 TO 1-15 | 62 | 4.2 | 6.9 | 5.4 | 1.4 | 1.5 | 1.9 | 4.3 | 0.0 | 52 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alfalfa, ratoon | 5-15 TO 7-15 | 62 | 0.9 | 11.6 | 9.2 | 0.1 | 0.2 | 8.0 | 8.8 | 6.5 | 217 |
| Banana, initial | 10- 1 TO 9-30 | 365 | 16.3 | 56.8 | 50.0 | 4.2 | 4.5 | 36.3 | 41.8 | 29.5 | 986 |
| Banana, initial | 5- 1 TO 4-30 | 365 | 16.4 | 57.3 | 44.8 | 1.1 | 4.5 | 27.8 | 32.6 | 16.2 | 755 |
| Banana, ratoon | 10- 1 TO 9-30 | 365 | 16.3 | 56.8 | 48.9 | 3.1 | 4.5 | 34.2 | 41.0 | 25.1 | 929 |
| Banana, ratoon | 5- 1 TO 4-30 | 365 | 16.4 | 57.3 | 43.5 | 0.5 | 4.5 | 26.2 | 31.5 | 15.7 | 711 |
| Cabbage | 11- 1 TO 1-31 | 92 | 7.6 | 10.4 | 8.2 | 3.1 | 3.1 | 3.5 | 6.0 | 0.7 | 95 |
| Cabbage | 5- 1 TO 7-31 | 92 | 1.9 | 17.2 | 14.4 | 0.3 | 0.2 | 12.3 | 14.5 | 9.2 | 334 |
| Cantaloupe | 10-15 TO 2-15 | 124 | 9.1 | 14.7 | 10.5 | 3.7 | 3.5 | 4.7 | 7.8 | 1.7 | 128 |
| Cantaloupe | 4-15 TO 8-15 | 123 | 2.6 | 22.9 | 16.6 | 0.2 | 0.3 | 14.2 | 17.1 | 11.7 | 386 |
| Dry Onion | 10-15 TO 2-15 | 124 | 9.1 | 14.7 | 13.3 | 3.0 | 3.5 | 6.8 | 11.1 | 2.1 | 185 |
| Dry Onion | 4-15 TO 8-15 | 123 | 2.6 | 22.9 | 21.2 | 0.2 | 0.3 | 19.4 | 22.6 | 16.3 | 527 |
| Eggplant | 10-15 TO 2-15 | 124 | 9.1 | 14.7 | 12.0 | 3.4 | 3.5 | 5.8 | 9.1 | 1.7 | 157 |
| Eggplant | 4-15 TO 8-15 | 123 | 2.6 | 22.9 | 19.7 | 0.3 | 0.3 | 17.7 | 21.1 | 14.7 | 481 |
| Ginger (AWD Potatoes) | 10- 1 TO 9-30 | 365 | 16.3 | 56.8 | 52.8 | 4.2 | 4.5 | 44.8 | 50.2 | 38.0 | 1217 |
| Ginger (AWD Potatoes) | 5- 1 TO 4-30 | 365 | 16.4 | 57.3 | 52.3 | 3.1 | 4.5 | 43.6 | 47.9 | 33.2 | 1184 |
| Lettuce | 11-15 TO 1-15 | 62 | 4.2 | 6.9 | 5.2 | 2.2 | 1.5 | 3.4 | 6.5 | 0.9 | 92 |
| Lettuce | 5-15 TO 7-15 | 62 | 0.9 | 11.6 | 9.1 | 0.2 | 0.2 | 9.6 | 10.8 | 7.7 | 261 |
| Other Melon | 10-15 TO 2-15 | 124 | 9.1 | 14.7 | 12.0 | 3.4 | 3.5 | 6.0 | 9.4 | 2.4 | 163 |
| Other Melon | 4-15 TO 8-15 | 123 | 2.6 | 22.9 | 19.6 | 0.3 | 0.2 | 17.6 | 20.8 | 14.5 | 478 |
| Pineapple, year 1 | 10- 1 TO 9-30 | 365 | 16.3 | 56.8 | 21.5 | 4.8 | 4.5 | 7.8 | 11.1 | 5.1 | 212 |
| Pineapple, year 1 | 5- 1 TO 4-30 | 365 | 16.4 | 57.3 | 23.9 | 4.2 | 4.5 | 11.6 | 15.6 | 8.3 | 315 |
| Pineapple, year 2 | 10- 1 TO 9-30 | 365 | 16.3 | 56.8 | 22.7 | 4.1 | 4.5 | 8.5 | 13.5 | 5.6 | 231 |
| Pineapple, year 2 | 5- 1 TO 4-30 | 365 | 16.4 | 57.3 | 24.4 | 3.4 | 4.5 | 11.6 | 14.6 | 6.9 | 315 |
| Pumpkin | 10-15 TO 2-15 | 124 | 9.1 | 14.7 | 11.7 | 3.4 | 3.5 | 5.6 | 8.8 | 1.7 | 152 |
| Pumpkin | 4-15 TO 8-15 | 123 | 2.6 | 22.9 | 19.0 | 0.3 | 0.3 | 16.9 | 20.0 | 14.2 | 459 |
| Seed, Corn | 10-15 TO 2-15 | 124 | 9.1 | 14.7 | 12.8 | 2.7 | 3.5 | 5.3 | 9.1 | 1.6 | 144 |
| Seed, Corn | 4-15 TO 8-15 | 123 | 2.6 | 22.9 | 20.8 | 0.2 | 0.3 | 17.5 | 20.5 | 14.7 | 475 |
| Sugarcane, New- year 1 | 10- 1 TO 9-30 | 365 | 16.3 | 56.8 | 58.3 | 3.5 | 4.5 | 45.1 | 51.6 | 35.8 | 1225 |
| Sugarcane, New- year 1 | 5- 1 TO 4-30 | 365 | 16.4 | 57.3 | 52.6 | 1 | 4.5 | 36.2 | 41.4 | 24 | 983 |
| Sugarcane, New- year 2 | 10- 1 TO 9-30 | 365 | 16.3 | 56.8 | 53 | 2.3 | 4.5 | 38.4 | 45.2 | 27.8 | 1043 |
| Sugarcane, New- year 2 | 5- 1 TO 4-30 | 365 | 16.4 | 57.3 | 53.3 | 0.6 | 4.5 | 37.9 | 43.3 | 26.4 | 1029 |
| Sugarcane, ratoon | 10- 1 TO 9-30 | 365 | 16.3 | 56.8 | 58.9 | 2 | 4.5 | 44.7 | 52.7 | 33.9 | 1214 |
| Sugarcane, ratoon | 5- 1 TO 4-30 | 365 | 16.4 | 57.3 | 58.3 | 0.5 | 4.5 | 43.7 | 49.4 | 30 | 1187 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sweet potatoes | 10- 1 TO 2-28 | 151 | 10.4 | 19.0 | 17.0 | 3.0 | 3.9 | 9.4 | 14.0 | 3.8 | 255 |
| Sweet potatoes | 4- 1 TO 8-31 | 153 | 3.4 | 28.2 | 26.2 | 0.2 | 0.4 | 24.1 | 28.7 | 20.6 | 654 |
| Taro | 10- 1 TO 9-30 | 365 | 16.3 | 56.8 | 62.9 | 12.7 | 4.5 | 119.0 | 131.0 | 111.0 | 3231 |
| Taro | 5- 1 TO 4-30 | 365 | 16.4 | 57.3 | 62.8 | 12.8 | 4.5 | 119.0 | 127.0 | 108.0 | 3231 |
| Tomato | 10-15 TO 2-15 | 124 | 9.1 | 14.7 | 12.8 | 3.1 | 3.5 | 6.4 | 10.1 | 1.7 | 174 |
| Tomato | 4-15 TO 8-15 | 123 | 2.6 | 22.9 | 21.1 | 0.3 | 0.3 | 19.3 | 22.3 | 16.4 | 524 |
| Watermelon | 10-15 TO 2-15 | 124 | 9.1 | 14.7 | 12.0 | 3.3 | 3.5 | 6.1 | 9.9 | 2.0 | 166 |
| Watermelon | 4-15 TO 8-15 | 123 | 2.6 | 22.9 | 19.3 | 0.3 | 0.3 | 17.3 | 20.1 | 14.4 | 470 |
| Coffee | 1- 1 TO 12-31 | 365 | 16.3 | 57.0 | 52.7 | 1.7 | 4.5 | 47.2 | 54.1 | 35.2 | 1282 |
| Dendrobium, pot, micro-sprink | 1- 1 TO 12-31 | 365 | 16.3 | 57 | 57 | 7.3 | 4.5 | 59.9 | 66.7 | 51.8 | 1627 |
| Dendrobium, pot, nursery spray | 1- 1 TO 12-31 | 365 | 16.3 | 57 | 57 | 10.8 | 4.5 | 185 | 213 | 158 | 5024 |
| Draceana, pot micro-sprink | 1- 1 TO 12-31 | 365 | 16.3 | 57 | 57 | 6.9 | 4.5 | 59.6 | 68.2 | 50.1 | 1618 |
| Draceana, pot, nursery spray | 1- 1 TO 12-31 | 365 | 16.3 | 57 | 57 | 9.7 | 4.5 | 184 | 212 | 158 | 4996 |
| Eucaluptus closed canopy | 1- 1 TO 12-31 | 365 | 16.3 | 57.0 | 57.0 | 1.1 | 4.5 | 51.9 | 63.0 | 36.1 | 1409 |
| Eucalyptus young | 1- 1 TO 12-31 | 365 | 16.3 | 57.0 | 35.2 | 1.5 | 4.5 | 24.9 | 32.2 | 14.1 | 676 |
| Guava | 1- 1 TO 12-31 | 365 | 16.3 | 57.0 | 51.8 | 1.5 | 4.5 | 45.6 | 52.6 | 34.5 | 1238 |
| Heliconia | 1- 1 TO 12-31 | 365 | 16.3 | 57.0 | 57.0 | 1.5 | 4.5 | 52.4 | 60.6 | 40.2 | 1423 |
| Kikuyu Grass | 1- 1 TO 12-31 | 365 | 16.3 | 57.0 | 57.0 | 1.9 | 4.5 | 56.5 | 64.2 | 41.6 | 1534 |
| Lychee | 1- 1 TO 12-31 | 365 | 16.3 | 57.0 | 51.9 | 1.2 | 4.5 | 45.4 | 54.2 | 33.5 | 1233 |
| Macadamia nut | 1- 1 TO 12-31 | 365 | 16.3 | 57.0 | 52.7 | 1.5 | 4.5 | 46.6 | 53.4 | 35.5 | 1265 |
| Ti | 1- 1 TO 12-31 | 365 | 16.3 | 57.0 | 57.0 | 1.5 | 4.5 | 52.4 | 60.6 | 40.2 | 1423 |

### 3.5 Summary and Conclusion

The objective of this section was to determine irrigation water requirement for all identified crops in the 10 irrigation systems. The purpose of determining irrigation water requirements was to prevent yield-reducing water stress during crop growth.

Daily water budget approach was used to calculate *IRR* based on the inputs of several types of data. Calculations required available historical daily rainfall and evapotranspiration data, soil physical properties, crop specific water use coefficients and average growing time for each selected crop. *IRR* was calculated for each system based on the planting season and the types of crops that were grown. Annual crops were calculated for wet (October to February), and dry (April to August) seasons, but perennial crops were calculated for the whole year. The irrigation requirements for the energy crops, consisting of Bana Grass, Seed Corn, Sugar Cane, and Leucaena, were also calculated for each system.

Irrigation water requirements differed temporally and spatially between systems due to the rainfall variation that occurs on each island. The windward sides of the islands generally need less *IRR* compared to leeward sides. Planting periods also affect the *IRR* values, the wet season requires less *IRR* and the dry season requires more *IRR*.

The *IRR* calculations show some crops, such as sugar cane and taro, needing more water than others, such as pine apple and cabbage, even within the same irrigation system. The variations in IRR for each system can vary with their location, planting periods and crops.

## 4. ASSESSMENT OF AGRICULTURAL POTENTIAL FOR 10 STUDIED IRRIGATION SYSTEMS

### 4.1 Overview

The ten studied irrigation systems were assessed through the integration of several methods, outlined below, culminating in weighted scores both without and with rehabilitation. First, available data for the studied systems were collected, including reports, records, and GIS data. Then site visits and field interviews were conducted by faculty-student research teams at each of the ten studied irrigation systems. Using this data, a conceptual model and scoring indicators were developed. An expert panel was convened to parameterize and validate the model. Finally, the ten studied irrigation systems were evaluated utilizing this model.

### 4.2 Data Sources and Collection Procedures

Data sources for the ten studied irrigation systems are summarized in Table 4.1. Primary data sources referenced in Table 4.1 are included on the CD-ROM accompanying this report.

Site visits were conducted for each of the ten studied irrigation systems (for specific dates for each visit, see “Field Trip Schedule.doc”on CD-ROM). Prior to each site visit, interviews were arranged with an irrigation system superintendent or equivalent, and also with several farmers who are served by the system. A system information packet was prepared prior to each visit for the research teams to reference in the field. This packet contained irrigation system and road maps, relevant information on each system from the Phase I report, as well as any other information from the sources listed in Table 4.1 thought to be of help *in situ* (see Irrigation System Field Trip Protocols, on CD-ROM).

Table 4.1 Summary of Studied System Data Sources

| Data Sources for Studied Systems | Citation or Reference |
|---|---|
| Phase I Report | HAWUDP Phase 1 |
| Site Visits | Field Visit Itineraries on CD-ROM |
| Interviews | Field Questionnaires on CD-ROM |
| GIS land | Report Section 2 |
| Soils | Report Sections 2.1.2 and 3.5 |
| Infrastructure | HAWUDP Phase 1, Field Questionnaires on CD-ROM and Report Section 4 |
| Other reports and records | CD-ROM |

Separate field questionnaires for farmers and irrigation system superintendents were created for use in field interviews, ensuring that all interviews were conducted in the same manner. Field interview questionnaires for system superintendents and system farmers are included in Figures 4.A-1 and 4.A-2 in Appendix 4-A, respectively, as well as included on the accompanying CD-ROM.

Post-visit, interviewees were mailed a follow-up letter or an e-mail, including a typed transcript of their interview. They were asked to review the transcript and make any desired corrections or amendments to their answers. Typed questionnaires, interviewee names and contact information, and any follow-up materials sent after the interview were maintained for each of the 10 studied systems. For typed interview versions, the names of the interviewees were not included in order to provide anonymity.

**4.3 Conceptual Model and Scoring Indicators**

Scholarly and agency publications on assessing irrigation system management were reviewed (see Section 8 references). This review did not find a readily adaptable tool with which to assess the 10 studied irrigation systems. It did provide background material for this study to develop an original framework and model specifically for Hawaii agricultural water planning.

A conceptual model (Figure 4.1) consisting of seven components (Table 4.2) was developed to illustrate the elements or forces acting on the future agricultural potential of an irrigated area. For each model component, a set of conceptual indicators, relevant to evaluating the long-run agricultural potential of irrigated areas, was identified. Furthermore, empirical indicators were identified for each conceptual indicator. The empirical indicators were developed based on the available data from the ten studied irrigation systems, taking into consideration the quantity and quality of the information available from various sources. Appendix 9.16 gives a detailed list of model indicators. Table 4-C (Appendix 4-C) lists indicator descriptors, including definition, rationale, and conceptual basis.

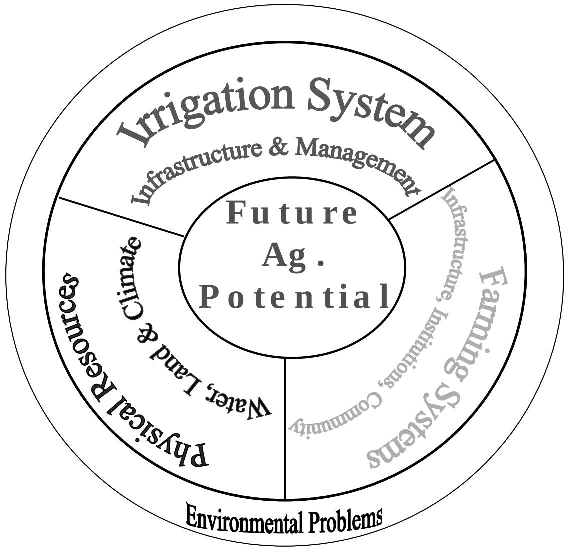


Figure 4.1 Model of Long-run Agricultural Potential of an Irrigated Area

Table 4.2 Summary of Scoring Indicators for Irrigation System Model

| Model Component | Conceptual Basis | Empirical Indicators | |
|---|---|---|---|
| | | No. | Description |
| Irrigation Water Supply | system-level water availability & reliability | 5 | water capacity, diversions; interannual & seasonal variability |
| Irrigation Infrastructure & Water Delivery | availability, condition, adequacy of facilities & water deliveries | 16 | infrastructure problems*; conveyance density, storage capacity; delivery efficiency, adequacy; water alternatives |
| Irrigation System Management | management effectiveness & quality of irrigation service | 16 | staff, equipment problems*; water planning, monitoring; financial resources; farmer participation, satisfaction |
| Land Resources | agricultural potential of lands & climate | 8 | soil productivity; erosion & drainage problems*; irrigation water requirement |
| Farm Infrastructure & Institutions | non-water facilities, conditions for farm viability & profitability | 10 | farm lots, security; land tenure; transportation; farm costs & marketing |
| Non-Agricultural Community | relations with non-farm residents in area | 15 | theft & related problems*; community awareness, conflicts; development pressures |
| Environmental Problems & Limitations | biophysical conditions negatively impacting irrigated agriculture | 12 | problems*: water & air quality, endangered or invasive species, water or land rights |

*Problems reported in interviews of system managers and/or farmers.
Taken together, these indicators represent potential factors most likely to influence an irrigation system in Hawaii, particularly the 10 studied systems for which data are available. Some indicators were specified in qualitative terms when accurate quantitative information could not be obtained. Given the data that could be collected, the empirical indicators were individually scored (0-10 point basis) for each of the 10 studied systems. Appendix 9.17 shows the assignment of numerical ratings for empirical indicators.

The averages of scored indicators for the ten studied irrigation systems are presented in Table 4.3. Most systems have fairly good land resources for irrigated agriculture. Water supply for irrigation is more variable, with the Molokai and Waimanalo systems scoring particularly low. All systems scored equally well on irrigation system management and relations with larger non-farm community. Based on the interviews conducted, environmental concerns were not a significant limitation at any system for the problems covered in the survey (see last row of Table 4.2). Although all the studied systems have been in operation for many years, average scores for farm infrastructure and institutions are surprisingly low.

The scores in Table 4.3 assume that each model indicator is equally important in determining long-run agricultural potential. This assumption is revised in subsequent analysis based on weights derived from a Delphi panel of experts (see section 4.5). Final weighted scores are given in section 4.6.

### 4.4 Impacts from Proposed System Rehabilitation

Phase I of the state agricultural water plan investigated rehabilitation of irrigation infrastructure for eight of the ten studied systems. The analysis included an assessment of needs describing current problems at a system, proposed capital improvements, and proposed maintenance improvements. These rehabilitation works are expected to improve water service and boost long-run agricultural potential of an irrigated area. This study assessed rehabilitation impacts by estimating the effects on empirical indicators in the irrigation scoring model. Only direct impacts were considered, that is, improvements to water management and irrigation service resulting immediately from the rehabilitation project. Any indirect impacts on irrigated agriculture (e.g., more productive farms or higher farmer assessments about system management) are speculative and were not incorporated in the with-rehabilitation analysis.

For this analysis, first information from the Phase I study, sometimes supplemented by other reports about a system, were compared with field visit results to identify the model indicators that would be impacted by rehabilitation of that system. If the proposed rehabilitation work was expected to solve a particular problem, the respective model indicator was re-scored to the top rating (10 points). Where a proposed “rehabilitation” is actually deferred maintenance (e.g., desilting), the problem is likely to recur in the future without changes in system management. In this case, an indicator was re-scored to the average rating for the other studied systems.

As discussed in the next section, the final irrigation system scoring model assigns weights to different model components and indicators within a component. Two components–Irrigation Water Supply, Irrigation Infrastructure and Water Delivery–account for half the potential scored points. Given the importance of these components and the direct relationships with system rehabilitation, special attention was given to re-scoring the indicators that would be affected by rehabilitation of a particular system. This included consulting all available references and collecting additional information from system managers.

Table 4.3 Average of Scored Indicators for 10 Irrigation Systems (0-10 point scale)

| Model Component | East Kauai | Kauai Coffee | Kekaha | Hamakua | Molokai | Upcountry Maui | West Maui | Waimea | Waiahole | Waimanalo |
|---|---|---|---|---|---|---|---|---|---|---|
| Irrigation Water Supply | 6.8 | 7.8 | 6.8 | 6.2 | 4.0 | 6.6 | 7.0 | 7.4 | 6.6 | 3.4 |
| Irrigation Infrastructure and Water Delivery | 5.2 | 7.0 | 7.7 | 7.8 | 8.2 | 6.9 | 6.3 | 8.1 | 8.1 | 8.3 |
| Land Resources | 7.8 | 8.5 | 6.8 | 6.8 | 8.2 | 7.0 | 6.6 | 8.8 | 8.8 | 8.1 |
| Farm Infrastructure and Institutions | 5.8 | 6.0 | 4.7 | 4.5 | 4.9 | 6.2 | 5.5 | 5.9 | 5.2 | 5.1 |
| Environmental Problems and Limitations | 8.5 | 8.2 | 8.5 | 9.1 | 8.2 | 9.0 | 7.7 | 9.9 | 9.8 | 9.8 |
| Irrigation System Management | 7.4 | 6.8 | 7.0 | 7.5 | 7.4 | 8.7 | 6.8 | 8.9 | 6.1 | 7.7 |
| Non-Agricultural Community | 7.9 | 7.0 | 6.5 | 7.8 | 8.8 | 7.4 | 6.7 | 8.0 | 8.6 | 8.3 |

Appendix 9.18 shows the without-rehabilitation ratings for the ten studied systems. The CD-ROM that accompanies this report contains Excel spreadsheets with re-scoring computations, including notes on the basis and data used for an indicator and system. Numeric results will be discussed in the next section in the context of total (weighted) system scores.

### 4.5 Delphi Panel Survey for Model Weights and Validation

Delphi Technique:

This study utilized an expert-based survey method known as the Delphi technique to develop, parameterize and validate models with which to project future agricultural conditions in Hawaii and evaluate the 10 studied irrigation systems. Section 8 provides some key references on Delphi and other techniques discussed in later sections.

A Delphi survey titled, "Delphi Survey on Scoring Model for Hawaii Irrigation Systems: Evaluating Future Agricultural Potential" (Appendix 4-B), was delivered electronically to a panel of experts on Hawaii irrigation systems. The experts (named in appendix list) were all well experienced professionals knowledgeable about different aspects of irrigated agriculture in Hawaii. The survey consisted of four rounds. Table 4.4 summarizes the survey. A more detailed description of the individual rounds follows. Appendix 4.B contains the questionnaire forms used in each round. The CD-ROM accompanying this report has Excel spreadsheets with Delphi panel responses and analyses.

Table 4.4 Summary of Irrigation Model Delphi Survey

| Round | Sections | Number of Participants |
|---|---|---|
| 1 | Rank major irrigation components<br>Rank conceptual indicators for each model component | 6 |
| 2 | Re-rank model components<br>Re-rank conceptual indicators for each component<br>Questions on aggregating data | 6 |
| 3 | Vote on weights for model components & indicators<br>Score hypothetical systems<br>Validate hypothetical situations | 5 |
| 4 | Re-vote weights for model components & indicators<br>Re-validate hypothetical systems<br>Personal information | 6 |

In Round 1 (Figure 4.B-1 in Appendix 4-B), the conceptual model was introduced and the panel was asked to rank its seven major components as well as to write related comments. Next the panel was asked to rank the importance of each conceptual indicator within the seven given model components, and to write any associated comments.

The purpose of Round 2 (Figure 4.B-2 in Appendix 4-B) was for the panelists to reassess their individual responses based on the collective panel results from Round 1. Panelists had the option of revising their responses to the same questions after being presented with the Round 1 results. Also in this round, the panel was introduced to the empirical indicators that would quantify the conceptual indicators rated in Round 1. In addition, questions were asked in Round 2 about aggregating data from different sources as well as the use of composite indicators to describe irrigation problems.

Specifically, panelists were asked how data with responses by both system managers and farmers should be aggregated–with separate indicators and a simple average of all responses, or by a weighted average of responses.

In Round 3 (Figure 4.B-3 in Appendix 4-B), the panel was again shown the results from the previous round. Next, the panel was asked to enter scoring weights, first for each of the model components and then for the associated empirical indicators within each component. Round 2 mean ranks were shown as a reference. A 100-point point weighting system was utilized. As a validation aid, two hypothetical Hawaii irrigation systems were described: an overall "good" system and an overall "bad" system. The hypothetical situations were a composite of actual conditions observed at the 10 studied systems. The respondents were asked whether the numeric scores, computed using the Delphi expert's weights for model components and empirical indicators, for the two hypothetical systems accurately reflected their qualitative evaluations of those systems.

Round 4 (Figure 4.B-4 in Appendix 4-B), began with panelists reviewing Round 3 results. Then, the panel was asked to revote the scoring weights, first for each of the components and then for the associated empirical indicators within each component. Round 3 mean ranks were shown for reference. Next, the total scores for the two hypothetical systems were re-evaluated by having panelists, comparing their scores to their qualitative evaluation of these systems. The survey concluded with a personal information section asking respondents to indicate their areas of expertise and the number of years worked in Hawaii related to that area of expertise.

Appendix 9.19 lists the final model weights estimated by the panel. The weights are standardized such that the points for all components sum to 100, and the weights for indicators within a component total 100. Table 4.5 summarizes the mean panel weights for various components.

The first three model components on water, infrastructure, and land resources dominate, together accounting for 71% of the model's weights. The preeminence given to natural resources in determining long-run agricultural potential is understandable. Within these top components, direct measures of water supply and demand received more points than other indicators. The other four model components were weighted much lighter, less than half that of the top components. Indicators on farm marketing, water rights, water quality/pollution, and farming prospects in the area were allocated more points in the less important components.

Table 4.5 Final Model Weights

| Component number | Component/Indicator description | Mean Panel Weight |
|---|---|---|
| 1 | Irrigation Water Supply | 31 |
| 2 | Irrigation Infrastructure and Water Delivery | 19 |
| 3 | Land Resources | 21 |
| 4 | Farm Infrastructure and Institutions | 7 |
| 5 | Environmental Problems and Limitations | 6 |
| 6 | Irrigation System Management | 9 |
| 7 | Non-Agricultural Community | 7 |

The final round (Round 4) of the Delphi survey included several questions about the validity of the model based on model scoring for two hypothetical irrigation systems. Most (83-100%) of the expert panelists indicated that the numeric scores were consistent with their qualitative evaluations. Numeric scores for the hypothetical systems ranged from 88-91 points for the "good" system down to 34-44 points for the "bad" system. This represents a reasonable range for the studied systems, all of which are in operation today. Results from the hypothetical scoring provide a scale to evaluate the long-run potential of individual systems, covered in the next subsection.

Table 4.6 presents the final system scores for the 10 studied systems, without and with rehabilitation, respectively. The scores are weighted to reflect the Delphi panels' assessment of relative importance of the seven model components and their respective indicators. The accompanying CD-ROM contains Excel spreadsheets that compute the irrigation scores for these systems.

Without the rehabilitation works proposed in Phase I of the agricultural water plan project, the scoring model finds the Waimea irrigation system on the Big Island has the best long-run potential with a weighted score of 77 points. This system now delivers an adequate supply of water and is not experiencing serious infrastructure or environmental problems. The next tier (scores of 68-71 points) is comprised of the Waiahole, Kauai Coffee, Kekaha, and West Maui systems. All were originally constructed to irrigate sugar plantations and have large diversion capacities for diversified agricultural uses. They are also located in leeward areas such that demand for irrigation water is relatively high, and infrastructure has not deteriorated as fast as windward systems. Some infrastructure at Waiahole has already been rehabilitated after the state government bought the system in 1999.

The bottom tier of the ten studied irrigation systems (64 points or lower) includes Molokai, Lower Hamakua, East Kauai, Upcountry Maui, and Waimanalo. Each of these systems experiences a serious problem(s) with water supply, although of a varied nature. With the exception of Molokai, the other four systems are in rainier areas, which reduces the benefits from irrigation. The infrastructure at the East Kauai system is severely run down.

Table 4.6 Weighted System Scores, With and Without Proposed Rehabilitation

| Irrigation System | Weighted Average Score with Rehab | Weighted Average Score without Rehab |
|---|---|---|
| Waimea | 82 | 77 |
| East Kauai | 72 | 63 |
| West Maui | 68 | 68 |
| Molokai | 76 | 64 |
| Waiahole | 71 | 71 |
| Hamakua | 66 | 64 |
| Upcountry Maui | 74 | 63 |
| Kauai Coffee | 69 | 69 |
| Waimanalo | 68 | 56 |
| Kekaha | 76 | 69 |
| **Mean** | 72 | 66 |

The Phase I project did not investigate rehabilitation at two private systems – Kauai Coffee and West Maui – so the scores for these systems do not change with rehabilitation. As mentioned above, the Waiahole system has been recently rehabilitated such that further improvements are directed at improving irrigation efficiency rather than addressing immediate problems.

Rehabilitation of the other seven systems would result in significant improvements and raise model scores by an average 8 points. The greatest gains would be experienced at the Molokai, Waimanalo, and Upcountry Maui systems. The Phase I proposal for these systems targets various enhancements to water supply. Rehabilitation of infrastructure at the East Kauai and Kekaha systems would also increase long-run agriculture potential, as indicated by the change in model scores.

### 4.7 Summary and Conclusion

Secondary information about the 10 studied irrigation systems was obtained by reviewing government reports and other publications. Primary data were collected from system records, field visits, on-site and remote interviews with irrigation managers and farmers. The information was used to evaluate system conditions (this section) and project future agricultural acreage (section 5).

A conceptual model of long-run agricultural potential for an irrigated area was developed specifically for this study. The model has seven major components, with a total 82 indicators measuring different aspects of the natural resource base, irrigation and farm infrastructure and management, environmental problems, and community relationships. Estimates of model parameters (weights) were derived from a Delphi survey of local experts. The empirical model scores an irrigation system on a 0-100 point basis.

Using the indicator model, the 10 studied systems were scored under current conditions, and with expected improvements from system rehabilitation proposed in Phase I agricultural water plan study. Without-rehabilitation scores ranged from a high of 77 points at Waimea, Big Island to a low of 56 points at Waimanalo, Oahu. Proposed rehabilitation works for 7 systems would raise scores by an average 8 points.

## 5. PROJECTING CROP ACREAGES TO YEAR 2030

### 5.1 Overview

Updating the state agricultural water plan required projecting irrigation water demands for five major islands and the 10 studied systems to the year 2030 in 5-year increments. The projections were to consider three alternative scenarios–most likely, optimistic, and pessimistic. Two Delphi surveys were conducted to develop the projections. Because Hawaii's agricultural sector is influenced by the state's overall economic conditions, one survey addressed the factors affecting Hawaii's macroeconomic climate. Three macroeconomic scenarios were developed from this analysis. The second survey focused on obtaining acreage projections for seven major crop groups.

### 5.2 Macroeconomic Scenarios

The project was to develop different scenarios of agricultural growth that will influence the future demand for irrigation water in Hawaii. First, the macroeconomic factors that drive performance of Hawaii's agricultural economy had to be identified. The Delphi technique was used for these purposes. The Delphi technique is an expert-based survey method. Section 8 lists important references on Delphi and other forecasting techniques.

To have credible macroeconomic future scenarios using Delphi, a group of experts were convened as a panel. An initial list of potential panel members was developed by the research team with careful considerations on balancing panelists' areas of expertise and sectoral representation. To ensure full participation and limit survey drop-outs, the research team contacted the expert panelists, communicated to them the importance and value of participating in the project. Most of the panelists were well known to the to the research team and to the Hawaii community. From the initial list of 22 names, the final panel consisted of six members who agreed to participate. The panelists comprised a heterogeneous group which included one bank economist, 4 university professors, and one state government economist.

Once the panelists had agreed to participate, the team designed the Delphi questionnaire rounds and issues to address in building scenarios for Hawaii agriculture in two periods, 2005-2015 and 2005-2030. Based on literature review and macroeconomic studies, the project team designed five Delphi rounds described below.

For Round 1, an initial model (Figure 5.1) was created to illustrate important macroeconomic relationships affecting Hawaii's agricultural economy. Potential macroeconomic drivers were divided by origin–U.S. and Hawaii. The U.S. drivers were grouped: 1) private sector growth influences energy costs and capital investments, 2) related macroeconomic factors that influence agricultural demand and supply and 3) military and foreign policy. The Hawaii drivers were grouped by 1) state and local government policy, 2) tourism and development and 3) population trends, demographics, labor force and lifestyle.

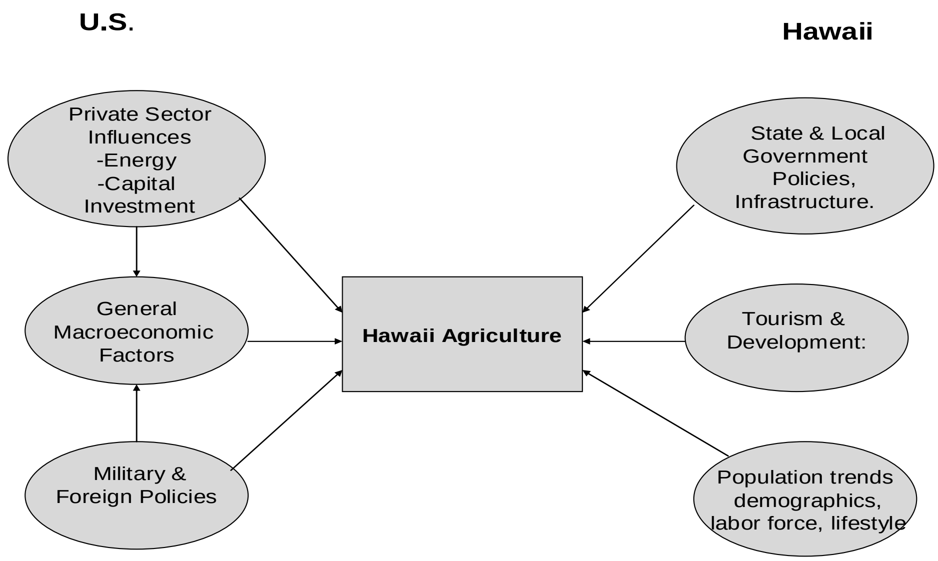


Figure 5.1: Relationship between Important Macroeconomic Factors that Affect the Future Supply and Demand of Hawaii Agricultural Products

### 5.2.1 Delphi Panel Survey

The expert panel of economists was surveyed over five rounds, shown in Table 5.1.

Table 5.1: Summary of Macroeconomic Delphi Survey

| Rounds | Survey Sections | No. of Respondents |
|---|---|---|
| 1 | Causal relationships between Hawaii's agricultural economy and macroeconomy. Macroeconomic drivers that impact it. | 6 |
| 2 | Results from Round 1. Consensus among panelists on 10 most important indicators for agriculture. | 6 |
| 3 | For each indicator, determine the linkages affecting Hawaii agriculture and identify as tend or uncertainty. Specify key descriptors for most likely, optimistic and pessimistic scenarios for indicators. Identify linkages among the selected indicators. | 4 |
| 4 | Reassess Round 3 responses to reach a consensus. Review Round 3 linkages and validate the most likely scenario for credibility and coherence | 5 |
| 5 | Validate optimistic and pessimistic scenarios developed from descriptors provided for credibility and coherence. Validate whether scenarios represent a reasonable range of uncertainty and plausibility. | 4 |

For Round 1, the panelists were asked to validate the causal relationships depicted in Figure 5.1. Based on this diagram the panelists were asked to verify and identify the key macroeconomic indicators under each group and how it impacted Hawaii's economy or agriculture. Indicators for each group and a description of how it may affect the economy were provided to the panelists and they were asked to rate the importance of these indicators. They were also asked to address any factors that may have been omitted or to describe how the factors affect the economy in a way they regarded as more appropriate. Furthermore, the panelists were asked to indicate their comments for any part of the Round 1 exercise. Details on macroeconomic indicators can be accessed from Appendix 9.20.

The purpose of Round 2 was to provide the panelists with the results from Round 1 so that a consensus can be reached on the important macroeconomic factors affecting Hawaii's agriculture. A consensus was not reached in Round 1. Frequency distribution statistics of Round 1 results were presented and panelists were asked to revote. A comment box was provided to state their reasons for comments or disagreements.

After the first two rounds, the ten most important macroeconomic indicators were determined. In Round 3, the panelists examined the top ten indicators and determined the linkages among the various indicators that they thought would affect the growth of Hawaii's agricultural sector. In this round, the panelists were asked to accomplish three things. First, the panel was to identify if an indicators was a trend or uncertainty. A trend may be thought of as the most likely, or expected case, while an uncertainty is some thing or event that is inherently difficult to predict. The second step was to identify key descriptors for each indicator corresponding to the most likely, optimistic and pessimistic scenarios. For example, "interest rate" could be labeled "stable" in the most likely scenario while under the optimistic scenario it could be a "borrower's market". Finally, the panelists were asked to identify linkages among the various indicators. They were provided the opportunity for comments, which were shared among the panel in the following round.

In the Round 4 the panelists were fed back the results from the third round. These showed that a consensus was not reached on whether each factor was a trend or uncertainty. Therefore, the panelists were asked to reassess their responses in an attempt to reach a consensus. They were also asked to review the linkages in the Figure 5.2 flow diagram developed from Round 3 responses, and comment on the aspects affecting Hawaii's agricultural sector. Lastly, the panelists were asked to evaluate the credibility and coherence of the most likely scenario developed by project investigators using the descriptors provided by the panelists' Round 3 responses

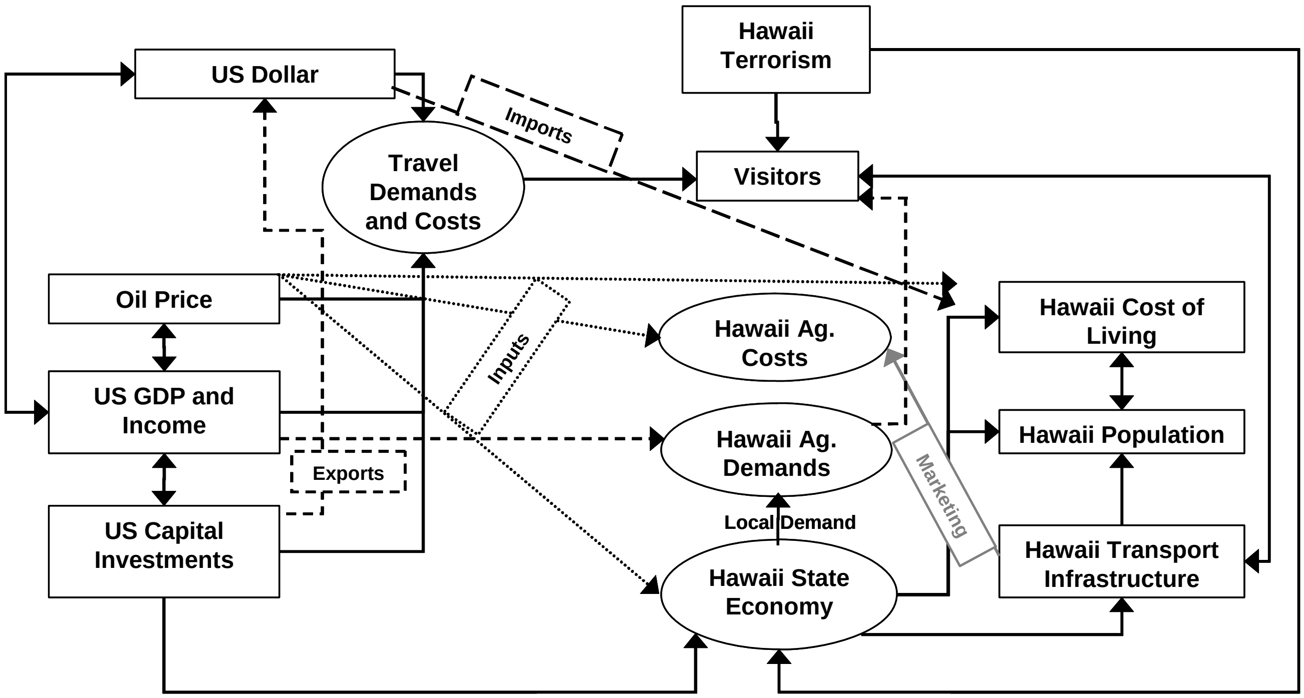


Figure 5.2: Hawaii Macroeconomic-Agriculture Linkages

In the fifth and final round of the macroeconomic Delphi exercise, results of Round 4 were provided to the panelists showing a consensus had been reached on whether each indicator was a trend or uncertainty. Optimistic and pessimistic scenarios were presented, developed by the project investigators panelists' responses and comments on indicators and their descriptors. Similar to Round 4, the panelists were asked to validate the optimistic and pessimistic scenarios by voting on their credibility and coherence. The panelists were also asked to validate whether or not the scenarios represented a reasonable range of uncertainty and plausibility.

The results of this fifth Delphi survey were combined with those from previous rounds to develop final descriptions of the three macroeconomic scenarios for growth of Hawaii's agricultural sector, given below. These scenarios were used as one input to a second Delphi panel to project crop acreages to 2030 (next subsection).

**Final Macroeconomic Scenarios from Delphi Survey**

1) *Most Likely Scenario:* The U.S. economy and consumer incomes expand at a moderate rate. This increases the domestic demand for vacations to Hawaii. However, in the medium term, capacity constraints slow growth in the number of visitors. Additional investment is expected to

relieve these constraints and sustain moderate growth in domestic visitors over the long run. Demand by foreign tourists is more uncertain due to volatility in the value of the U.S. dollar. Also, higher oil prices in the medium term raise the costs of travel, holding down growth in foreign visitors. Hawaii continues to benefit from global mobility in capital, and capital investment stimulates growth in the state's economy. But such growth also leads to continuing increases in housing prices and the local cost of living. For Hawaii's agriculture, downward pressures on the dollar increase exports to foreign countries, particularly emerging economies. Moderate growth in the mainland economy, Hawaii visitors and resident population increases domestic demands for ag-based products. But higher oil prices raise local farm production and agricultural marketing costs. Inadequate transportation facilities and congestion in shipping limit market expansion for the next ten years. Overall, Hawaii agriculture grows at a modest rate but its share of the state's economy continues to shrink as emerging sectors come to dominate future economic growth.

2) *Optimistic Scenario:* Hawaii agriculture flourishes with the establishment of a bioenergy industry and development of new tropical specialty crops. Rational planning and upgrades of local infrastructure, including new modes of transportation, improve transport of goods and the overall efficiency of marketing agricultural products. This revitalization of Hawaii agriculture feeds on strengths in the global economy. As the price of oil levels off and concerns about terrorist attacks fade, the American economy experiences accelerating growth, charged by high-tech investment and cyclical booms. Gradual depreciation in the U.S. dollar stimulates growth in exports including high-value agricultural products from Hawaii. It also spurs growth in Hawaii's visitor industry, especially an influx of upscale tourists. This fuels the demand for niche agricultural products. The local population grows at a moderate rate, enough to keep pace with labor demands. Increases in the cost of living in Hawaii slow and, given the strong economy, locals enjoy higher personal incomes. This sustains steady expansion in demand for locally produced agricultural products. Moderating prices for energy and other inputs are offset by rising wages. Overall, the expansion of Hawaii's agricultural sector outpaces the rest of the state's economy.

3) *Pessimistic Scenario:* The mainland economy endures long periods of little or no growth with sharp cyclical downturns. Volatility in the U.S. dollar creates uncertainty and hinders economic expansion through exports. Capital investment slows, further depressing the economy of the U.S. mainland and Hawaii. The price of oil continues its upward trend in the near-term period, with occasional spikes above $100 per barrel due to unpredictable supply and slow development of cheaper alternative energy sources. The global demand for vacation travel wavers with energy prices. Credible terrorist threats to high-profile tourism sites in Hawaii damage our image as a vacation destination. For Hawaii residents, increases in the cost of living outpace growth in earnings. Local lifestyles deteriorate from overcrowding and poor transportation due to inadequate public investment in infrastructure projects. In this depressed economic environment, Hawaii's farmers face serious challenges. Agricultural production and marketing costs rise due to higher prices for energy, and other inputs. This is compounded by problems of finding adequate water and farm workers. Competition from low-cost producers squeeze the profitability of local agribusiness. Growth in export markets for high-value agricultural products slows. Local sales of agricultural products falter and food imports increase. Hawaii's total agricultural output experiences a gradual decline through the year 2030.

## 5.3 Crop Acreage Projections by Island

### 5.3.1 Background

Several sources of background information were gathered as a baseline for projecting crop acreage by island, including DBEDT and USDA projections, HASS data, and current NASS acreages by island. Figures 5.3 and 5.4 show 1990-2004 annual growth in Hawaii for 7 crop groups, and projected 2005-2015 annual growth for select U.S. crops, respectively. The 7 Hawaii groupings are based on HASS's classification of currently grown crops and may exclude some minor specialty crops like herbs. The information was presented to the expert panel at the beginning of the Delphi panel survey (section 5.32). Table 5.2 shows current land use for the 10 studied irrigation systems, calculated from GIS analysis.

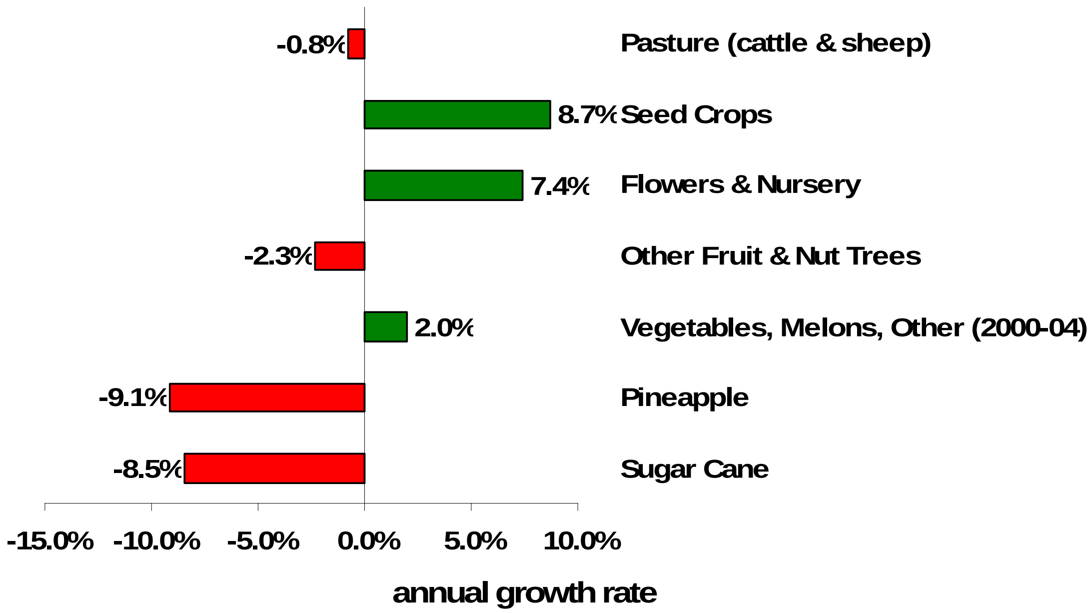


Figure 5.3: 1990-2004 Annual Growth in Hawaii for 7 Crop Groups

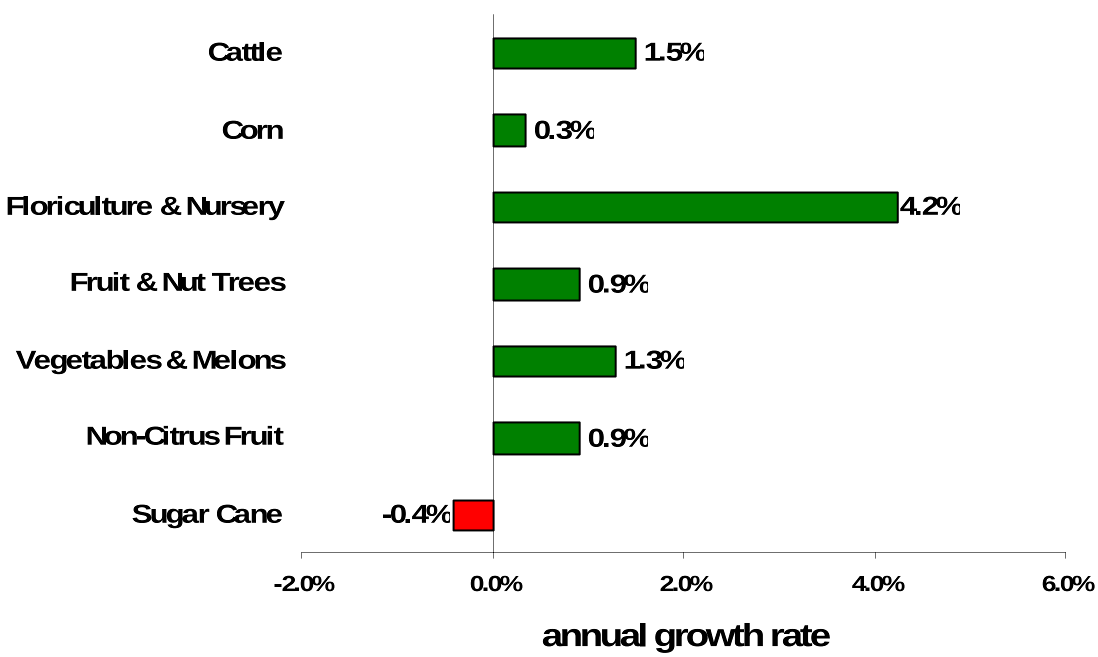


Figure 5.4: USDA Projected 2005-2015 Annual Growth for Selected U.S. Crops

Table 5.2: Acreages by Land Cover or Crop Type for 10 Studied Irrigation Systems

| System | Crop Type | Acres |
|---|---|---|
| East Kauai | Bananas, Eggplant | 305 |
| | Sandalwood (Monastery) | 286 |
| | Taro | 232 |
| | Pasture | 4377 |
| Kauai Coffee | Coffee | 3712 |
| | Corn | 87 |
| | Pasture | 488 |
| Kekaha | Corn | 6517 |
| Lower Hamakua | Banana | 2 |
| | Eucalyptus | 67 |
| | Pasture | 3629 |
| Molokai | Coffee | 294 |
| | Cucumber | 40 |
| | Papaya | 40 |
| | Pasture | 542 |
| Waiahole | Banana | 152 |
| | Pineapple | 551 |
| West Maui | Orchid | 12 |
| | Sugar Cane | 1509 |
| Waimanalo | Banana | 25 |
| | Mango | 1 |
| | Orchid | 4 |
| | Pasture | 111 |
| Waimea | Pasture | 556 |

### 5.3.2 Delphi Panel Survey

A survey on "Developing Crop Projections for Hawaii's Agricultural Future Using the Delphi Technique" was distributed electronically to a panel of Hawaii agriculturalists and agribusiness leaders. For projection purposes, current Hawaii crops were grouped into seven categories: sugar, pineapple, seed crops, vegetables and melons, fruit and nut trees, nursery and flowers, and pasture. The agricultural panel was surveyed in five rounds, summarized in Table 5.3. A more detailed description of the individual rounds follows.

In Round 1 of the survey (Appendix 5.B, Figure 5.B-1), seven drivers of Hawaii agricultural growth were presented to the panel. The panel was asked to indicate which drivers will be important for a given crop group. A second section examined agricultural growth rates for two time periods, 2005-2015 and 2016-2030. Background information was provided from DBEDT projections, USDA projections, and agricultural statistics on crop acreage from HASS. The panel was then asked to indicate expected growth (above average, average, below average, flat, decline) for each crop group during 2005-2015 and relative growth (higher, same, lower) over 2016-2030. The final section of Round 1 focused on the location, by island, of Hawaii agriculture. For the five major islands, the panel was asked to indicate whether a driver is expected to cause higher/lower than average growth (or even decline).

Table 5.3: Summary of Crop Projection Delphi Survey

| Round | Survey Sections | No. of Participants |
|---|---|---|
| 1 | • Rank drivers of agricultural growth<br>• Vote state expected crop growth rates for 2005-2015, 2015-2030<br>• Vote crop growth allocation by island | 17 |
| 2 | • Re-rank drivers of agricultural growth<br>• Re-vote state expected crop growth rates for 2005-2015, 2015-2030<br>• Re-vote crop growth allocation by island | 16 |
| 3 | • Re-vote state expected crop growth rates for 2005-2015, 2015-2030<br>• Scenarios' impact on growth rates<br>• Vote growth allocation by crop group<br>• Validation of hypothetical situations | 16 |
| 4 | • Validation of state expected crop growth rates for 2005-2015, 2015-2030<br>• Vote projected acreage by crop group<br>• Re-vote acreage allocation share by island<br>• Vote crop distribution by irrigation system | 13 |
| 5 | • Professional background questions<br>• Validation of share allocation by island for selective crops<br>• Validation of crop distribution by irrigation system<br>• Vote impact of rehabilitation on irrigation systems' score | 8 |

Subsequent survey rounds were used to estimate growth rates in crop acreages to 2030. In Round 2 (Figure 5.B-2 in Appendix 5-B), the panel quantified state growth rates after reviewing Round 1 results. Round 3 (Figure 5.B-3 in Appendix 5-B) allocated growth in crop acreages by island from the Round 2 state growth rates. In Round 4 (Figure 5.B-4 in Appendix 5-B), the panel was fed back growth rates from the previous rounds and presented the alternative macroeconomic scenarios. Where previous rounds showed significant convergence, the panel was asked for a validation vote. If there was a lack of significant convergence, the survey asked for a revised vote. There was also a vote on the impact of the macroeconomic scenarios in increasing or decreasing expected growth rates. Round 5, (Figure 5.B-5 in Appendix 5-B) validated the previous round's responses, and the panel voted on the impact of rehabilitation on acreage growth at the studied irrigation systems.

### 5.3.3 Survey Results with Discussion

The first round of the Delphi survey assessed the importance of seven potential drivers of future growth in Hawaii agriculture. These included

- land availability and cost
- water availability and cost
- other production inputs including technology
- transportation industry structure, modes, routes including transhipment, cost
- development of ag-based products and processing technology
- Hawaii markets, consumer demand and competition
- other (mainland, foreign) markets, consumer demand and competition.

The analysis evaluated the relative importance of the different drivers for the seven crop groups and whether a driver would positively/negatively cause above/below average growth on a given island.

Table 5.4 summarizes the responses by the Delphi panel. Water availability and cost was considered an important driver for all crops except pineapple and pasture. However, transportation and markets were viewed as more important for diversified crops. The panel did not find water would be a significant factor favoring growth on any particular island.

Table 5.4: Important Drivers for Hawaii Agriculture Identified in Delphi Survey, by Crop Group and for Five Major Islands

| **Breakdown (by)** | **Agr. Growth Driver** | | | | | | |
|---|---|---|---|---|---|---|---|
| | land | water | other inputs | trans-portation | product tech. | Hawaii markets | other markets |
| **Crop Group** | *V=very important, i=important* | | | | | | |
| sugar | | i | | | i | | i |
| pineapple | | | | | | | i |
| seed crops | i | i | i | | | | |
| veg. & melons | i | i | | i | | V | |
| fruit & nut trees | i | i | | V | i | i | V |
| nursery & flowers | i | i | | V | | | V |
| pasture | i | | | V | | i | i |
| **Major Islands** | + positive factor, – negative factor | | | | | | |
| Kauai | – | | + | | + | + | – |
| Oahu | | | + | + | + | + | + |
| Molokai | + | | | | | | – |
| Maui | – | | + | | + | + | + |
| Hawaii | + | | + | + | + | + | + |

The Delphi panel estimated growth rates for acreage by crop group for the Most Likely macroeconomic scenario, and variation due to alternative scenarios. The growth rates are from base year 2004, for which actual crop acreages were available during the Delphi survey. These are presented in Table 5.5. The Most Likely projection has acreage growth of 1-2% per year, which is consistent with Hawaii DBEDT (2004) economic projections for the agricultural sector. By crop, the strongest growth is expected in seed crops, vegetables and melons, and fruit and nut trees. The Delphi panel of agriculturalists estimated that the optimistic/pessimistic scenario could raise/lower annual growth rates by 0.5 percentage points. This is more conservative than the qualitative projections from the economics Delphi panel, where agricultural output could grow faster than the rest of the economy (optimistic) or experience an absolute decline (pessimistic).

Table 5.5: Estimated Growth Rates for Hawaii Crop Acreages under 3 Macroeconomic Scenarios

| **Crop Group** | **2005-2015 Growth** | | | **2016-2030 Growth** | | |
|---|---|---|---|---|---|---|
| ***Scenarios*** | *Pessimistic* | *Most Likely* | *Optimistic* | *Pessimistic* | *Most Likely* | *Optimistic* |
| Sugar | 0.4% | 0.9% | 1.4% | 0.6% | 1.1% | 1.6% |
| Pineapple | -0.6% | -0.1% | 0.4% | -0.7% | -0.2% | 0.3% |
| Seed Crops | 1.4% | 1.9% | 2.4% | 1.6% | 2.1% | 2.6% |
| Vegetable & Melons | 1.2% | 1.7% | 2.2% | 1.3% | 1.8% | 2.3% |
| Fruit & Nut Trees | 1.2% | 1.7% | 2.2% | 0.8% | 1.3% | 1.8% |
| Nursery & Flowers | 1.1% | 1.6% | 2.1% | 1.3% | 1.8% | 2.3% |
| Pastures | -0.1% | 0.4% | 0.9% | 0.0% | 0.5% | 1.0% |

Appendix 9.21 shows projected changes in crop acreages at the 10 studied irrigation systems, without proposed rehabilitation. In the Most Likely Scenario, the greatest increases were expected at the Big Island systems, with Lower Hamakua adding about 2,500 ac. and Waimea about 2,000 ac. by 2030. The two irrigation systems on Oahu (Waiahole, Waimanalo) and the Molokai IS had the lowest projected growth in acreage without rehabilitation.

In the agricultural Delphi survey, few panelists responded to questions on how much rehabilitation would affect future agricultural acreage in the 10 studied irrigation systems. As a replacement, graphical and statistical analyses investigated possible relationships between system assessment scores (see subsection 4.6) and without-rehabilitation acreage projections. A fairly strong correlation (r=0.76) was found between

x = score of long-run agricultural potential without rehabilitation
y = 2030 projected crop acreage (excluding pasture and bioenergy) without rehabilitation as a percentage of system irrigable acreage.

The y variable adds projected acreage to 2004 base cultivated acres (computed in GIS analysis), then divides by irrigable acres (from GIS). Figure 5.5 plots the data. A simple regression was estimated to quantify the linear relationship, shown in figure. The system assessment derived expected increase in scores (change in x) from rehabilitation. This with used to predict the impact on future acreage utilization (change in y), and thus estimate 2030 crop acreage with rehabilitation.

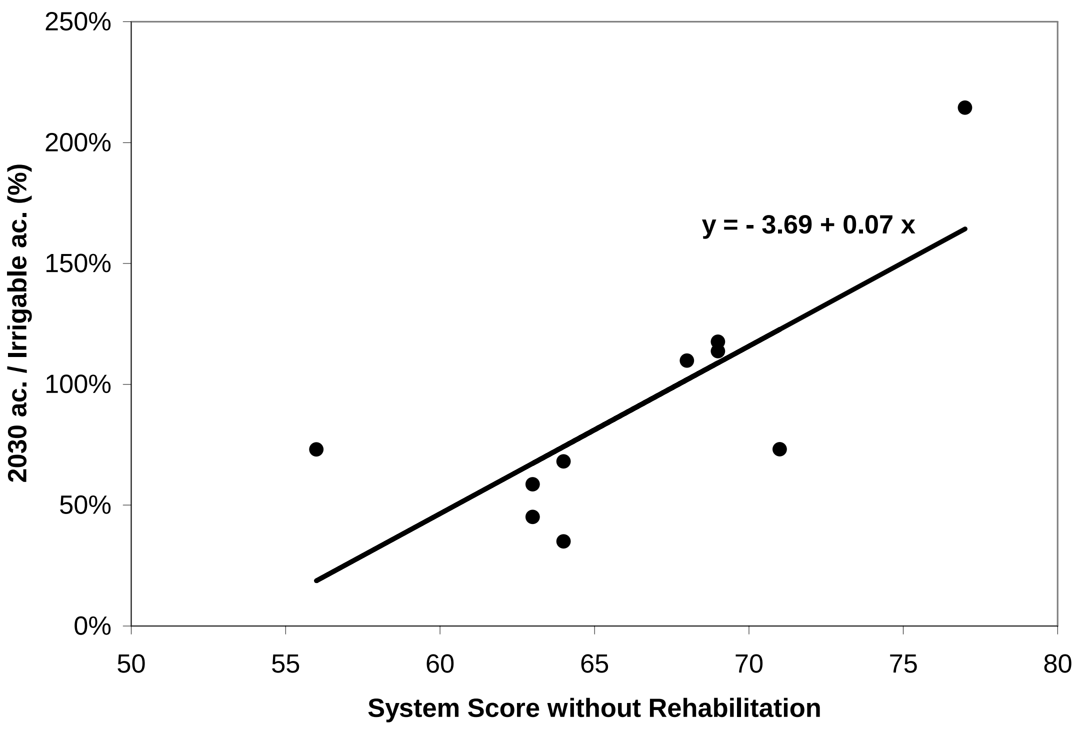


Figure 5.5: Relationship between Irrigation System Scores and Projected Acreage without Rehabilitation

## 5.4 Bioenergy

### 5.4.1 Introduction

Bioenergy is the generation of energy from organic matter. Bioenergy feedstock production is the harvesting of organic matter that is destined for bioenergy generation. Organic matter is converted via chemical processes into bioenergy. The feedstock contains energy in the form of carbon, fixed through the process of photosynthesis in the crop or tree. Bioenergy feedstock stores this carbon in the form of fiber, sugar, starch, or oil. The appropriate amounts of sunlight, nutrients and water can optimize biomass productivity by enhancing feedstock growth. Irrigation, then, could play a large role in bioenergy feedstock production.

This section of the report assesses land availability and irrigation water requirements for producing bioenergy crops in the state of Hawaii over the next 25 years. The water requirements are contingent upon crop composition and the amount of land cultivated. Planted bioenergy feedstock acreage, in turn, depends on potential profitability and some basic physical constraints.

### 5.4.2 How Bioenergy Fits into Hawaii's Present Energy Market

Bioenergy can potentially meet two of Hawaii's energy market needs, electricity and transportation fuel. Bioenergy can supplement traditional sources of transportation fuels and electricity and help decrease Hawaii's dependence on imported and unstable energy sources.

Biomass energy, generated from crops, agricultural waste or by-products, accounted for 1.9% of Hawaii's total 2003 energy consumption. Bagasse, plant fiber deemed waste after sugar has been extracted from the cane, and other fiber-based waste materials have accounted for Hawaii's biomass energy until present. In Hawaii there is no present cultivation of feedstock explicitly for bioenergy production. Bioenergy may become a significant part of state's energy consumption mix if bioenergy crop cultivation is economically feasible.

#### 5.4.2.1 *Electricity*

Fiber bioenergy crops, through the process of combustion, can generate electricity. This is a proven process that can incorporate many types of crops, trees, and agricultural or byproduct waste. Biodiesel and ethanol can also produce electricity. The Hawaiian Electric Company (HECO) has expressed a strong commitment to energy diversification and is paying particular attention to bioenergy.

#### 5.4.2.2 *Transportation Fuels*

Sugar and starch bioenergy crops can be converted into ethanol, a biofuel that is blended with gasoline in various concentrations. E10 refers to an energy mix of 1 part ethanol for 9 parts gasoline. E85 is another popular blend. Virtually all commercial vehicles that can run on unleaded gasoline are able to run on E10. Pipelines are not an option for ethanol delivery because ethanol is water-soluble. Pure ethanol is typically delivered by trucks to distribution and storage terminals for blending. The blend is again delivered by trucks to gas stations. The technology for fiber crop conversion into ethanol is not yet commercially viable, though many scientists predict that such a technology should be available in the next few years. Oil-based bioenergy crops can be converted into biodiesel, a biofuel that is blended with diesel in various concentrations. B20 and B100 are the two of the more popular blends. (B100 is pure biodiesel.) Biodiesel is also transported to distributors and retailers via trucks.

Transportation in Hawaii accounts for roughly a third of the state's aggregate energy consumption. Hawaii consumed one trillion gallons of petroleum in 2001. In 2004, Hawaii Governor Linda Lingle issued an administrative rule committing the state to a market in which E10 makes up 85 percent of the unleaded gasoline sold, effective April 2, 2006.

Some recent studies attest that by relying on proven commercial technologies and using only raw sugars and molasses from unused lands, Hawaii could supply 90 million gallons of ethanol per year in the short term and 400 million gallons as a mature industry (Stillwater Associates, 2003). The market for bioenergy is so large that over-production is not a possibility in the near future, provided that prices stay competitive with that of fossil fuels.[1] This study's analysis suggest that such prospects are unrealistic.

### 5.4.3 Obstacles to Bioenergy Development in Hawaii

Various obstacles involved in bioenergy production constrain its large-scale development in Hawaii, listed in Table 5.6. The physical elements, namely land availability, water availability, road transportation and irrigation infrastructure, pose major constraints to bioenergy production.

Coupled with land availability is the willingness of landowners to cultivate or lease their land for cultivating bioenergy crops. Hawaii Bioenergy LLC is an international consortium that is presently researching the feasibility of bioenergy cultivation in Hawaii. Three of Hawaii's largest landowners–Grove Farm, Maui Land and Pineapple, Kamehameha Schools–organized the hui, which is no longer functional. Such initiatives and cooperatives may be a step forward for ensuring large contiguous tracts of land, which are necessary for bioenergy crop cultivation. This will also distribute the risk among various stakeholders, diminishing uncertainty to some extent.

Table 5.6: Barriers to Biofuel Development in Hawaii

| Constraints | Agricultural Production Factor |
|---|---|
| **Physical** | • Land availability (large contiguous tracts)<br>• Road transport capacity<br>• Water availability<br>• Irrigation infrastructure status |
| **Technological** | • Development/deployment of higher yield crops<br>• Mechanical harvesting/processing for energy crops |
| **Legal/Permitting** | • Water rights<br>• Water permits |
| **Financial Risks** | • Labor availability<br>• Real estate market price pressure<br>• Production—imported feedstock vs. fixed cost<br>• Water cost<br>• Lead time for feedstock production vs. market demand (security of demand)<br>• Climate change/seasonality vs. demand |

Source: Rocky Mountain Institute (2006).

### 5.4.4 Sources and Methods

#### 5.4.4.1 *Survey of Agricultural and Bioenergy Experts*

The 2006 Hawaii Agriculture Conference was held from October 26-27. The conference hosted a bioenergy workshop on October 27 and attracted experts and parties interested in bioenergy

[1] The common assumption at present is that oil prices must be $60/barrel or above to make biofuel development economically feasible. See International Energy Agency (2005).

development in Hawaii. About 2/3s of the 150 attendees filled out the survey during a lunch break. The detailed survey results are given in Figure 5.C.1 in Appendix 5-C. The survey results were weighted based on respondents' self-assessment on their knowledge of agriculture and bioenergy.

**5.4.4.2** ***Geographical Information Systems (GIS) approach to projected bioenergy crop acreage***
Projections of bioenergy crop production in Hawaii should consider location. In particular, large parcels need to be identified since experts estimate that minimum acreage requirements for ethanol production are 2,000-5,000 acres per operation. The availability of water is a second consideration. While there are various bioenergy feedstock crops that can grow without irrigation, this study focused exclusively on crops that require irrigation. It is likely that bioenergy feedstock production in the short term will only occur in locations of existing irrigation systems. And only lands still zoned by government as agriculture need be considered for long term, large scale production.

GIS data were collected on large landholdings, plantation lands as of 1978-80, and current boundaries of the state's Agricultural land use district (Hawaii Office of Planning, 2006). The analysis identified parcels greater than 1,000 acres that were previously used for sugarcane or pineapple. Land no longer in the Agricultural District was excluded. Large parcels whose owners show no discernible interest in agriculture were also eliminated. The remaining areas were mapped with GIS by island and the respective available acres quantified. These estimates are a more realistic assessment of potential bioenergy crop acreage than other projections based on state energy demands.

### 5.4.5 Results and Findings

**5.4.5.1** ***Survey Results on the Likelihood of Bioenergy Cultivation***
The survey asked the likelihood that bioenergy crops (sugar, starch, fiber or oil based crops) would be cultivated in Hawaii by the year 2030. 68% of those surveyed believed that significant bioenergy crop cultivation is highly likely (Figure 5.6). Only 2% believe that it is not likely. The respondents were also asked for their opinion on the most likely start date and how long it would take for bioenergy crop cultivation to reach its maximum potential.

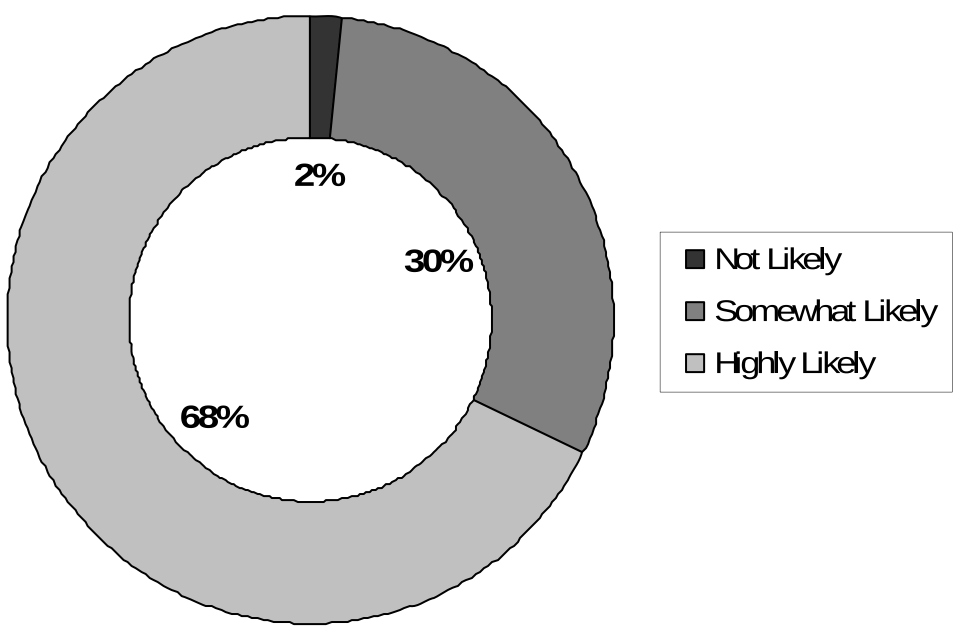


Figure 5.6: Likelihood of Bioenergy Crop Cultivation in Hawaii in the Year 2030

After evaluating irrigation systems in place and land use possibilities, the survey asked respondents about the likelihood of bioenergy crops in 5 production areas of 4 islands. The results are shown in Figure 5.7. No single area emerged as a top location for irrigated bioenergy production. It should be noted that some survey respondents suggested Molokai and Lanai as other potential areas.

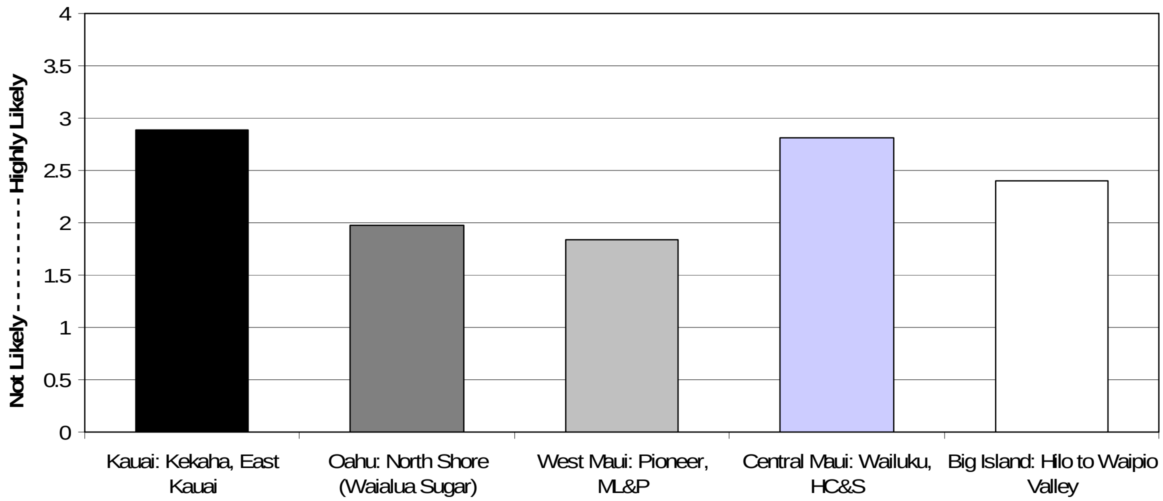


Figure 5.7: Irrigation System Likelihood for Bioenergy Crop Cultivation

Based on a prior study (Kinoshita and Zhou, 1999), the survey narrowed down possible bioenergy crops to sugar for ethanol production, corn starch for ethanol production, banagrass or Leucaena as fiber for biomass energy production. Many scientists and experts have identified oilseed bearing crops and trees for the production of biodiesel. However, none of the crops have been extensively researched in Hawaii nor seem economically viable for the commercial production of biodiesel (Kinoshita, 2006). Since this study focused on agricultural water demands (i.e., irrigated crops only), Eucalyptus was excluded since it would likely not be irrigated. Leucaena and banagrass, on the other hand, do require irrigation (Kinoshita and Zhou, 1999).

For potential irrigated plants, the survey asked respondents about the likelihood of Hawaii farmers cultivating particular crops. Their opinions are given in Figure 5.8. Sugarcane was judged the most likely crop for bioenergy, followed by banagrass and Leucaena.

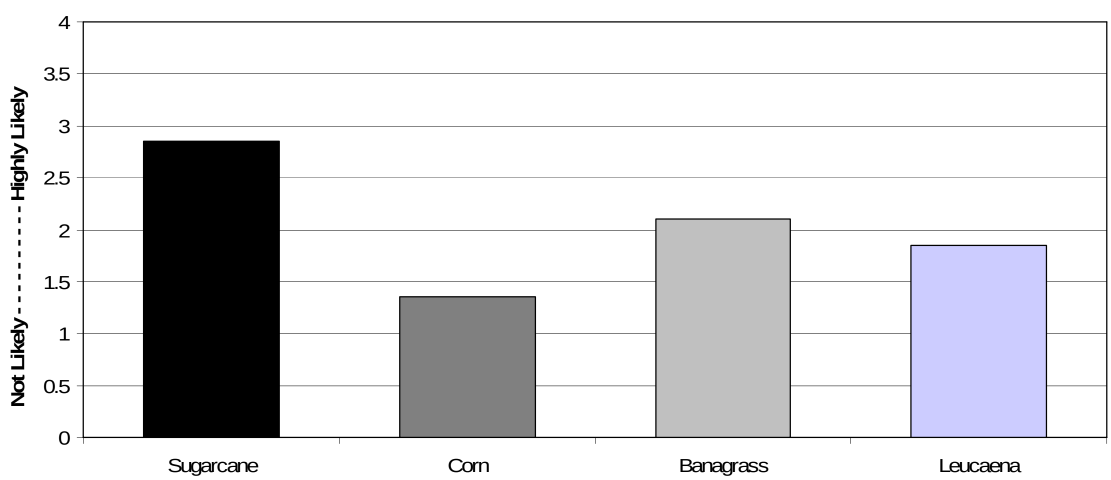


Figure 5.8: Likelihood for Hawaii Production of Specific Bioenergy Crops

**5.4.5.2** ***Scenarios from Macroeconomic Delphi Panel***

Future scenarios were developed with the macroeconomic Delphi panel. Abstracts of these scenarios that are most pertinent to bioenergy production are given below. These scenarios were considered in developing projections of land use acreage for bioenergy production.

In the *optimistic scenario*, Hawaii agriculture will flourish with the establishment of a bioenergy industry. Local infrastructure will improve bioenergy transport systems. The price of oil will level off, but bioenergy demand will remain strong at the same time. Moderate prices for energy restrain agricultural production costs, increasing profits.

In the *pessimistic scenario*, the price of oil will continue to rise, with occasional spikes above $100 per barrel due to unpredictable supply and high costs of alternative energy sources. There will be inadequate public investment to address transportation problems. Inadequate labor and water make bioenergy crops impossible to cultivate.

In the *most likely scenario*, visitors and resident population will increase domestic demand for agriculturally-based products, providing a steep opportunity cost for converting those products to bioenergy crops. Higher oil prices, however, will raise local farm production and agricultural marketing costs. The high oil prices coupled with a maturing public conscience will make bioenergy crops an appealing option.

**5.4.5.3** ***GIS Maps of Potential Bioenergy Production Lands***

Bioenergy crop cultivation is contingent upon water availability (status quo irrigation systems and crop water requirements) and land availability (ownership). The study developed the maps in Figures 5.9-5.13 by overlaying GIS data on former plantation lands, irrigation systems, and large landholdings (Hawaii Office of Planning, 2006). The aggregate acreage is utilized for the bioenergy acreage projections covered in the next subsection. Due to lack of data, the analysis did not exclude small diversified crop areas currently being cultivated that may not be displaced by new bioenergy enterprises.

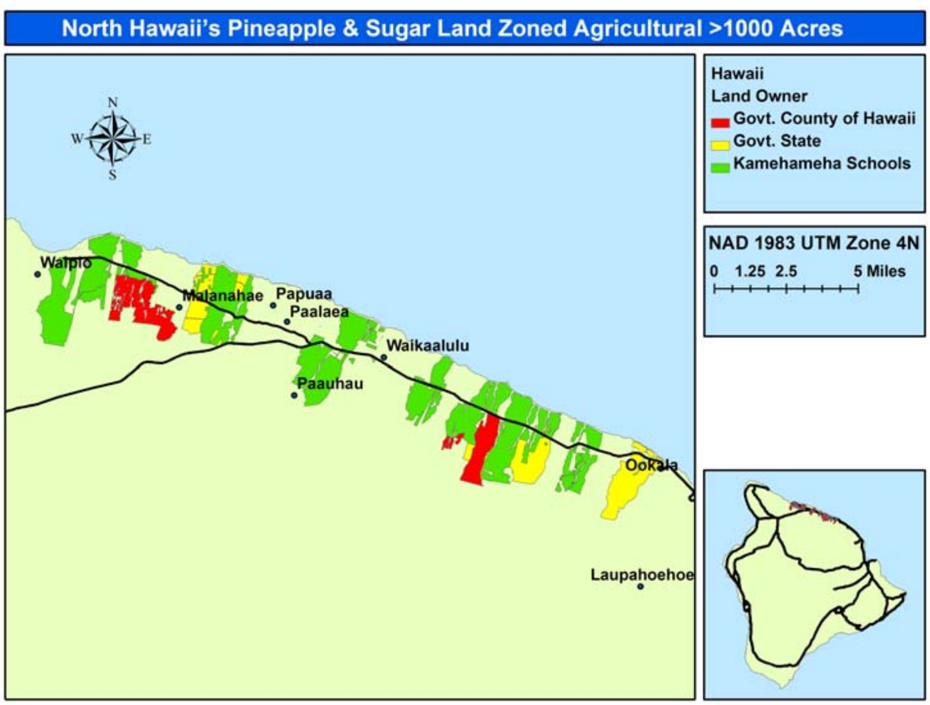


Figure 5.9A. Potential Bioenergy Crop Land on the Big Island (North)

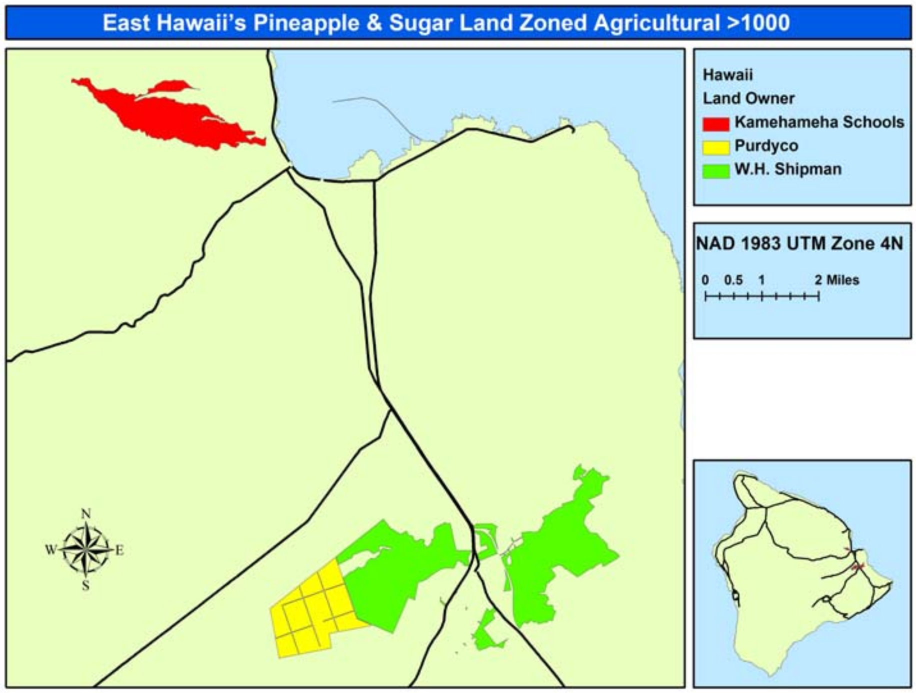


Figure 5.9B. Potential Bioenergy Crop Land on the Big Island (East)

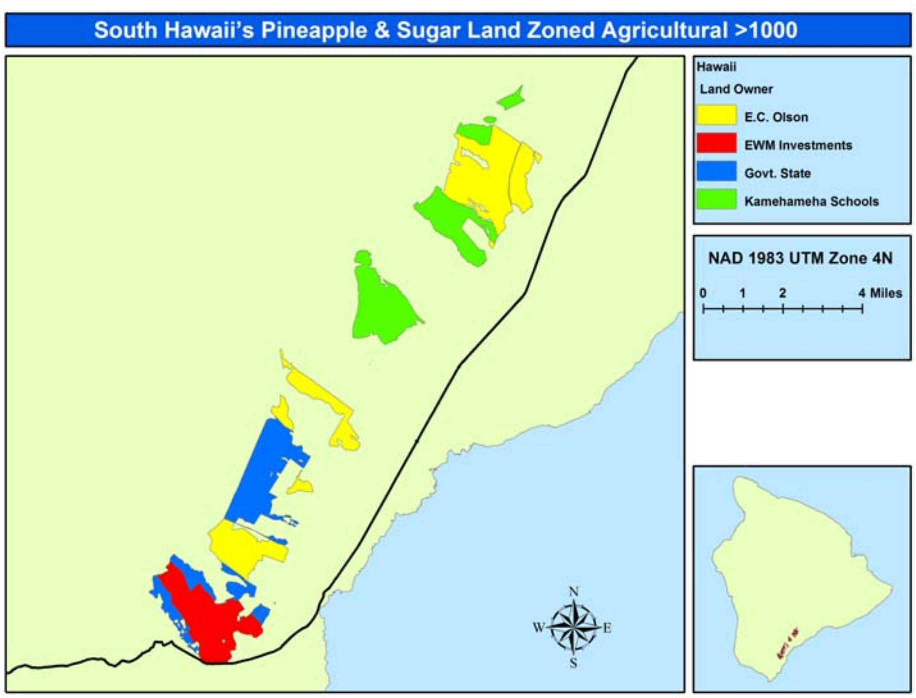


Figure 5.9C. Potential Bioenergy Crop Land on the Big Island (South)

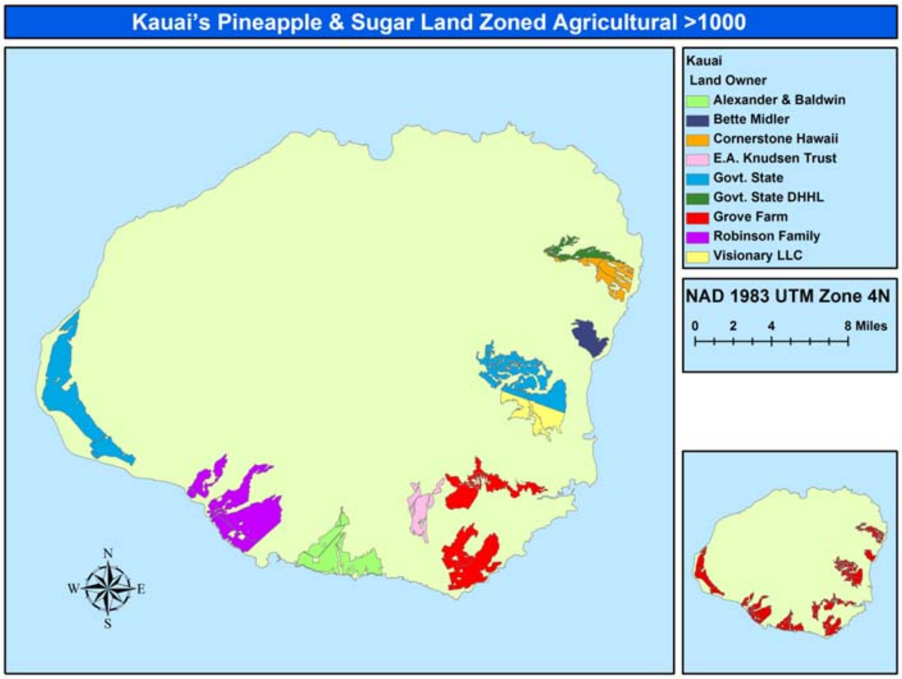


Figure 5.10. Potential Bioenergy Crop Land on Kauai

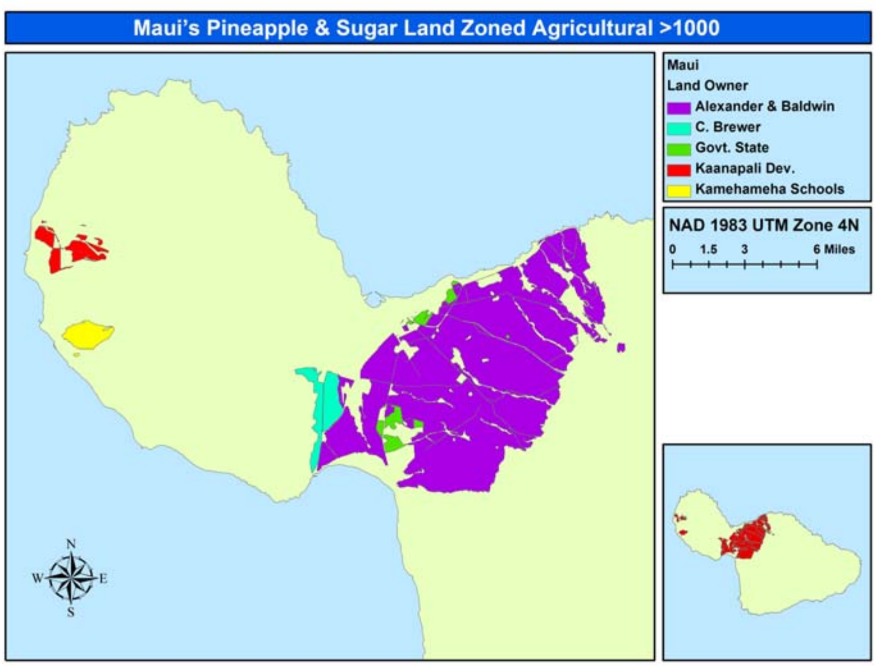


Figure 5.11. Potential Bioenergy Crop Land on Maui

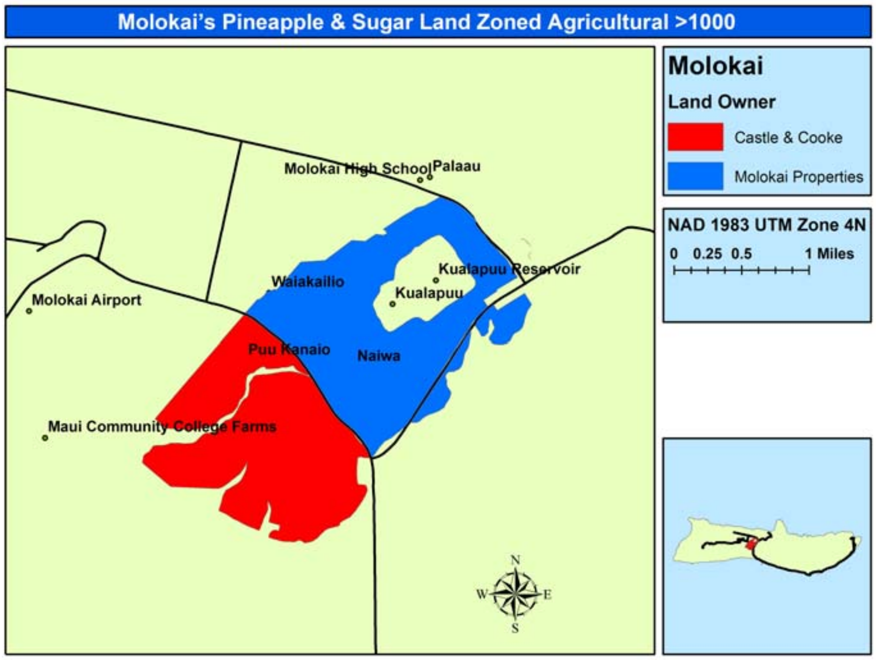


Figure 5.12. Potential Bioenergy Crop Land on Molokai

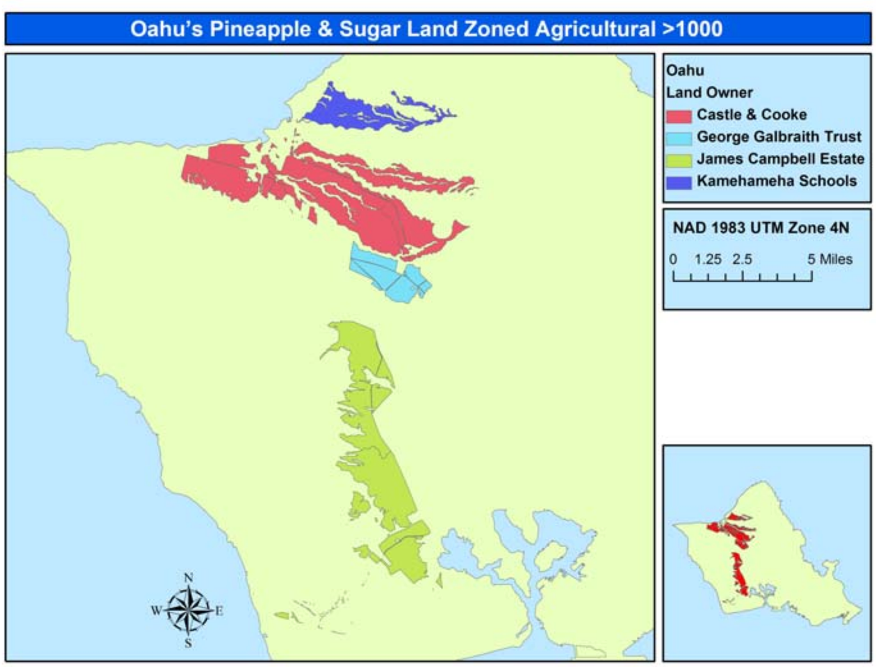


Figure 5.13: Potential Bioenergy Crop Land on Oahu

#### 5.4.5.4 *Scenarios of Bioenergy Acreage Projections*

Based on the above maps, there are 137,000 acres of former plantation lands still in the Agricultural District that could conceivably be used for bioenergy field crops (Table 5.7). This does not include land from plantations that closed prior to 1978, and landholdings less than 1,000 acres. Also excluded are lands where sugarcane, seed crops, or coffee is currently being grown. Most of these are privately owned lands.

Table 5.7. Availability of Former Plantation Lands for Bioenergy, by Island

| Island | Total (acres) | Private (acres) | Public (acres) |
|---|---|---|---|
| Big Island | 35,917 | 27,299 | 8,618 |
| Kauai | 32,915 | 22,149 | 10,766 |
| Maui | 43,480 | 42,371 | 1,109 |
| Molokai | 2,102 | 2,102 | 0 |
| Oahu | 22,259 | 22,259 | 0 |
| Statewide | 136,673 | 116,180 | 20,493 |

It is unrealistic that all of these lands could be brought back into production. This analysis further eliminated former plantation areas where extremely large investments in infrastructure would be needed (e.g., Molokai) and where landowner interest in agriculture is absent based on publicly available information. Our optimistic projection (Table 5.8) is for 53,000 acres statewide that might be farmed in bioenergy crops. The Big Island and Kauai have the most potential, at around 20,000 acres each. Oahu has an optimistic estimate of 10,000 acres.

Molokai is projected to have no significant bioenergy production due to lack of irrigation water. Water for bioenergy crops would need to come from distant and remote valleys; the financial and environmental costs appear to be too high a barrier for increasing irrigation water supply for bioenergy.

Table 5.8. Projected Acreage in New Bioenergy in Year 2030, by Island

| Island | Optimistic (acres) | Mid-Point (acres) | Pessimistic (acres) |
|---|---|---|---|
| Big Island | 20,771 | 10,386 | 0 |
| Kauai | 19,377 | 9,689 | 0 |
| Maui | 2,951 | 1,476 | 0 |
| Molokai | 0 | 0 | 0 |
| Oahu | 10,147 | 5,074 | 0 |
| Statewide | 53,246 | 26,623 | 0 |

* Excludes current sugarcane operations on Maui and Kauai.

The amount of bioenergy acreage in Table 5.8 that lies within the 10 studied irrigation systems is shown in Table 5.9. Substantial bioenergy production is not projected to occur in 6 of the 10 studied systems. The Lower Hamakua IS has the largest area that could be used for bioenergy, about 17,000 acres. Another 9,400 acres at the Kekaha, East Kauai, and Waiahole systems are considered feasible for bioenergy. The pessimistic scenario assumes no development of a bioenergy crop industry in Hawaii. The mid-point between the pessimistic and optimistic scenarios is used to represent the "most likely" scenario.

Table 5.9: Projected Acreage in New Bioenergy in Year 2030 for 10 Studied Irrigation Systems

| Irrigation System | Optimistic (acres) | Mid-Point (acres) | Pessimistic (acres) |
|---|---|---|---|
| Waimea | 0 | 0 | 0 |
| East Kauai | 2,200 | 1,100 | 0 |
| West Maui | 0 | 0 | 0 |
| Molokai | 0 | 0 | 0 |
| Waiahole | 1,600 | 800 | 0 |
| Lower Hamakua | 16,997 | 8,499 | 0 |
| Upcountry Maui | 0 | 0 | 0 |
| Kauai Coffee | 0 | 0 | 0 |
| Waimanalo | 0 | 0 | 0 |
| Kekaha | 5,621 | 2,811 | 0 |

* Excludes current sugarcane operations on Maui and Kauai.

#### 5.4.5.5 *Water Requirements for Bioenergy Crops*

Coefficients of irrigation water requirements for the energy crops (i.e., banagrass, seed corn, sugar cane, and Leucaena) were estimated for each studied irrigation system. The physiologically similar crops of sudangrass and eucalyptus were used to estimate coefficients for banagrass and Leucaena, respectively. Drip irrigation was assumed for corn, sugar cane, and leucaena. A sprinkler irrigation system with large guns was assumed for banagrass. System irrigation efficiency was assumed to be 85 percent for drip irrigation and 70 percent for large-gun sprinklers. These coefficients are given in the next section (Tables 6.2 by irrigation system and Table 6.3 by island). Projected bioenergy crop acreages are multiplied by irrigation water requirements to project irrigation water needed.

Among the 10 studied irrigation systems, the analysis of available lands indicated Lower Hamakua, Kekaha, East Kauai and Waiahole have potential for bioenergy production. Respective demands for irrigation water are discussed in the next section. The estimates of bioenergy acreage developed here establish a plausible range of future outcomes. They help identify likely areas of substantial growth might occur.

### 5.5 Summary and Conclusion

Electronic Delphi panel surveys were used to develop macroeconomic scenarios for future growth of Hawaii agriculture, and to project crop acreages to 2030. The expert panel of economists identified 10 sectoral drivers and respective descriptors for Most Likely, Optimistic, and Pessimistic scenarios. Qualitative descriptions of these scenarios were developed from their analysis. Agriculture grows at a modest rate in the Most Likely scenario, which is consistent with DBEDT's economic projections. A second panel of agriculturalists assessed the importance of microeconomic drivers for agricultural production. Water availability and cost was of some importance for most crop groups but not a significant factor for any particular island. The panel estimated that crop acreage would grow 1-2% per year for most groups. For the 10 studied irrigation systems, the greatest increases in cultivated area were expected at the two Big Island systems.

A survey of agricultural and bioenergy experts indicated that it is highly likely for some bioenergy production to occur by the year 2030. From an assessment of large agricultural landholdings available, bioenergy crop production could reach an optimistic potential of 53,000 acres. The pessimistic scenario is little or no growth. Given considerable uncertainty, it is difficult to project a most likely scenario. The midpoint between the optimistic and pessimistic scenarios is taken as an intermediate estimate. The Big Island and Kauai have the most potential land for bioenergy crops, about 20,000 acres each. Of the 10 studied irrigation systems, Lower Hamakua, Kekaha, East Kauai and Waiahole had the largest areas available for bioenergy crops.

# 6. PROJECTED CROP DEMANDS FOR IRRIGATION WATER TO YEAR 2030

### 6.1 Overview

Projecting crop demand for irrigation water over the next 25 years combines estimates of irrigation water requirements by crop (section 3) with projections of acreages for 7 crop groups (section 5). Projections are by island and for 10 studied irrigation systems under three macroeconomic scenarios–Most Likely, Optimistic, and Pessimistic. Qualitative descriptions of these scenarios are given in subsection 5.2.

### 6.2 Irrigation Water Requirements for Crop Groups

Section 3 developed estimates of farm-level irrigation water requirements for a number crops and varied practices. Table 6.1 summarizes the assumptions to aggregate (simple average) water requirements for the 7 crop groups. The average coefficients were used to project water demands for the studied irrigation systems. Projections by island used the simple average of IRR for the studied systems on that island. Tables 6.2-6.3 present the averaged coefficients used in projecting total water demands.

Table 6.1: Assumptions for Developing Crop Group Water Requirement Coefficients for Studied Irrigation Systems

| Crop Group | Individual crops | Water Coefficients | Number of Coefficients Averaged |
|---|---|---|---|
| Sugar | sugarcane | Year 1&2 by Spring and Fall plantings | 4 |
| Pineapple | pineapple | Year 1&2 by Spring and Fall plantings | 4 |
| Vegetables & Melons | eggplant, ginger, lettuce, other melon, pumpkin, sweet potatoes, taro, tomato, watermelon | Spring and Fall plantings | 24 |
| Seed Crops | seed corn | Spring and Fall plantings | 2 |
| Fruit & Nut trees | banana, coffee, guava, lychee, macadamia nuts | initial and ratoon crops, bananas only | 8 |
| Floriculture & Nursery | dendrobrium, draceana, heliconia, ti | micro-sprinkler and nursery spray | 6 |
| Pasture | Kikuyu grass | | 1 |
| Bioenergy | sugarcane, corn | see above crops | 6 |

Table 6.2: Estimated Seasonal Irrigation Water Requirements, by Irrigation System (1000 gal/ac)

| Crop Type | Kekaha | Kauai Coffee | East Kauai | Waiahole | Waimanalo | Molokai | West Maui | Up Country Maui | Waimea | Lower Hama kua |
|---|---|---|---|---|---|---|---|---|---|---|
| Sugar | 1109 | 748 | 156 | 1070 | 433 | 1843 | 1663 | 745 | 978 | 371 |
| Pineapple | 296 | 130 | 6 | 268 | 59 | 575 | 523 | 145 | 213 | 56 |
| Vegetables & Melons | 639 | 490 | 242 | 625 | 336 | 990 | 910 | 475 | 516 | 383 |
| Seed Crops | 323 | 215 | 61 | 310 | 130 | 554 | 503 | 213 | 246 | 145 |
| Fruit & Nut trees | 1064 | 682 | 107 | 1050 | 406 | 1770 | 1632 | 726 | 977 | 336 |
| Floriculture & Nursery | 2712 | 2351 | 1326 | 2685 | 1687 | 4204 | 3734 | 2148 | 2354 | 1815 |
| Pasture | 1544 | 1052 | 212 | 1534 | 679 | 2428 | 2259 | 1113 | 1339 | 570 |
| Bioenergy (Ethanol) | 881 | 470 | 108 | 697 | 243 | 1279 | 1113 | 467 | 633 | 234 |

Table 6.3: Estimated Seasonal Irrigation Water Requirements, by Island (1000 gal/ac)

| Crop Group | Kauai | Oahu | Molokai | Maui | Hawaii |
|---|---|---|---|---|---|
| Sugar | 671 | 751 | 1843 | 1204 | 674 |
| Pineapple | 144 | 163 | 575 | 334 | 135 |
| Vegetables & Melons | 457 | 481 | 990 | 692 | 449 |
| Seed Crops | 200 | 220 | 554 | 358 | 196 |
| Fruit & Nut trees | 617 | 728 | 1770 | 1179 | 656 |
| Floriculture & Nursery | 2130 | 2186 | 4204 | 2941 | 2085 |
| Pasture | 936 | 1107 | 2428 | 1686 | 955 |
| Bioenergy (Ethanol) | 486 | 470 | 1279 | 790 | 433 |

## 6.3 Crop Irrigation Water Demands – by Irrigation System

Table 6.4 summarizes the final projections of agricultural irrigation water demand for the 10 studied irrigation systems, excluding bioenergy crops but including pasture. In the Most Likely scenario, the Kekaha IS shows the largest growth in demand, increasing an average 0.77 MGD per year over 25 years. The least growth is expected at the Waimanalo and East Kauai systems. In the Optimistic scenario, growth in water demands is about double the Most Likely case. The Pessimistic scenario projects no growth in irrigation demands at all systems.

The phase I study for the agricultural water plan proposed rehabilitation projects for 8 of the 10 studied irrigation systems. Such improvements are expected to increase a system's long-run potential, which could stimulate crop cultivation and the respective demands for irrigation water. The far right column of Table 6.4 shows the estimated increase in 2030 demands from system rehabilitation. The Molokai IS could see a huge increase in water demand, almost 3 times more than projected Most Likely growth. Demand at the Kekaha system could also jump sharply.

The Table 6.4 projections are farm-level demands for water. Data are not available to estimate system efficiency in delivering water to farms. Therefore, it is not possible to compare projected water demands with water resources available at these systems.

Table 6.4: Projected Change in Irrigation Water Demand for 10 Studied Irrigation Systems, Without and With System Rehabilitation (million gallons per day)

| Scenario system | WITHOUT REHAB | | | WITH REHAB |
|---|---|---|---|---|
| | Avg. Annual 2005-2030 (MGD) | Total 2005-2015 (MGD) | Total 2016-2030 (MGD) | Additional 2030 Demand (MGD) |
| **Most Likely Scenario** | | | | |
| Kekaha | 0.77 | 7.81 | 11.53 | 8.05 |
| Kauai Coffee | 0.19 | 2.09 | 2.71 | n/a |
| East Kauai | 0.05 | 0.51 | 0.69 | 2.07 |
| Waiahole | 0.18 | 1.76 | 2.69 | 0.00 |
| Waimanalo | 0.04 | 0.40 | 0.58 | 1.96 |
| Molokai | 0.40 | 4.09 | 5.97 | 27.01 |
| West Maui | 0.25 | 2.76 | 3.48 | n/a |
| Upcountry Maui | 0.18 | 1.84 | 2.69 | 2.59 |
| Waimea | 0.54 | 5.51 | 8.07 | 1.25 |
| Lower Hamakua | 0.69 | 7.02 | 10.22 | 0.79 |
| **Optimistic Scenario** | | | | |
| Kekaha | 1.73 | 16.09 | 27.25 | |
| Kauai Coffee | 0.40 | 3.83 | 6.05 | |
| East Kauai | 0.09 | 0.90 | 1.44 | |
| Waiahole | 0.40 | 3.68 | 6.34 | |
| Waimanalo | 0.13 | 1.25 | 2.11 | |
| Molokai | 0.93 | 8.70 | 14.66 | |
| West Maui | 0.52 | 5.06 | 7.90 | |
| Upcountry Maui | 0.39 | 3.68 | 6.18 | |
| Waimea | 1.09 | 10.19 | 17.14 | |
| Lower Hamakua | 0.77 | 7.15 | 12.03 | |
| **Pessimistic Scenario** | | | | |
| Kekaha | -0.11 | -1.54 | -1.25 | |
| Kauai Coffee | 0.00 | -0.04 | -0.05 | |
| East Kauai | 0.01 | 0.10 | 0.16 | |
| Waiahole | -0.02 | -0.27 | -0.25 | |
| Waimanalo | 0.00 | 0.00 | 0.04 | |
| Molokai | -0.07 | -0.78 | -1.04 | |
| West Maui | 0.00 | -0.06 | -0.03 | |
| Upcountry Maui | -0.01 | -0.18 | -0.07 | |
| Waimea | 0.05 | -0.33 | 0.85 | |
| Lower Hamakua | -0.02 | -0.33 | -0.19 | |

After reviewing a draft of this report, a representative of the Hawaii Crop Improvement Association submitted an alternative estimate of growth in seed corn acreage at 8 studied irrigation systems (excluding Waimea and Lower Hamakua), plus other irrigated area(s) on the North Shore of Oahu. At the request of the study's sponsors, a separate water demand projection was computed based on the industry acreage estimates. The results are shown in Table 6.5. Compared with the Most Likely projections in Table 6.4, water demand at the Waiahole IS could be 1.43 MGD higher or 38% of total growth projected through 2030. Impacts at the other systems are less significant.

Table 6.5. Seed Corn Industry Acreage Estimates and Impact on Projected Irrigation Water Demands, Selected Areas

| Location | Industry Est. Area (ac.) | | Projected Water Demand (MGD)* | |
|---|---|---|---|---|
| | 2005-2015 Growth | 2016-2030 Growth | 2005-2015 Increase | 2016-2030 Increase |
| **Studied System** | | | | |
| Kekaha | 575 | 243 | 0.45 | 0.08 |
| Kauai Coffee | 150 | 200 | 0.07 | 0.08 |
| East Kauai | 475 | 455 | 0.08 | 0.07 |
| Waiahole | 1,685 | 475 | 1.40 | 0.33 |
| Waimanalo | 0 | 0 | 0.00 | 0.00 |
| Molokai | 100 | 100 | 0.14 | 0.12 |
| West Maui | 100 | 100 | 0.10 | 0.05 |
| Upcountry Maui | 250 | 250 | 0.14 | 0.14 |
| **No. Shore Oahu** | 200 | 250 | 0.17 | 0.21 |

*Difference compared to Most Likely scenario in Table 6.4 projections.

### 6.4 Crop Irrigation Water Demands – by Island

Table 5.5 reported estimated growth in acreage for 7 crop groups, which was allocated to different islands based on proportions estimated in the Delphi survey (see Appendix 9.22). These rates were applied to 2005 crop acreages to project cultivated area to 2030. Bioenergy crop areas were projected separately based on Table 5.8, assuming all new acreage comes online at once in 2010. Projected acreages were multiplied by the respective coefficients in Table 6.3 to estimate island irrigation water demand over the next 25 years. Water demand is defined to be the irrigation water requirement to achieve full (non-deficit) production, regardless of whether any irrigation system is currently available.

Projected water demands for all crops under the three scenarios are presented in Table 6.6. Oahu and Molokai are the islands with the smallest irrigation water demand, the Big Island and Maui the largest. Growth in water demand depends on the scenario. In the Most Likely scenario, demand increases by about 50% for Kauai, Oahu and Molokai by 2030. Relative growth is lower (15-20%) for Maui and the Big Island due to much larger base demands. In the Optimistic scenario, demand roughly doubles for Kauai, Oahu and Molokai, with 30-40% growth on Maui and the Big Island. In the Pessimistic scenario, demand is relatively flat, with growth less than 10% over 25 years.

Pasture dominates water demand amongst the seven crop groups. Yet pasture is a low valued crop and thus far less likely to be irrigated. Projections of bioenergy are highly uncertain at this time. Table 6.7 shows irrigation water demand for all crops excluding pasture and bioenergy. Demand growth is much lower in MGD terms. However, relative growth is similar, with the exception of Molokai.

Table 6.6 Projected 2005-2030 Irrigation Water Demands (MGD) by Island under Three Macroeconomic Scenarios, All Crops

| Island | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|
| *Most Likely Scenario* | | | | | | |
| Kauai | 60 | 77 | 82 | 85 | 88 | 92 |
| Oahu | 21 | 29 | 31 | 32 | 33 | 34 |
| Molokai | 25 | 28 | 31 | 33 | 36 | 38 |
| Maui | 184 | 194 | 201 | 204 | 208 | 212 |
| Big Island | 210 | 228 | 235 | 241 | 247 | 253 |
| **Total State** | **500** | **556** | **579** | **595** | **612** | **629** |
| *Optimistic Scenario* | | | | | | |
| Kauai | 60 | 93 | 101 | 107 | 114 | 121 |
| Oahu | 22 | 37 | 40 | 42 | 44 | 47 |
| Molokai | 25 | 30 | 36 | 41 | 46 | 52 |
| Maui | 185 | 202 | 214 | 222 | 231 | 241 |
| Big Island | 211 | 245 | 257 | 267 | 278 | 291 |
| **Total State** | **502** | **608** | **647** | **679** | **714** | **751** |
| *Pessimistic Scenario* | | | | | | |
| Kauai | 59 | 61 | 63 | 64 | 64 | 65 |
| Oahu | 21 | 22 | 22 | 22 | 23 | 23 |
| Molokai | 24 | 25 | 26 | 26 | 26 | 26 |
| Maui | 183 | 186 | 189 | 188 | 187 | 186 |
| Big Island | 209 | 211 | 214 | 215 | 216 | 218 |
| **Total State** | **497** | **505** | **514** | **515** | **516** | **518** |

Table 6.7 Projected 2005-2030 Irrigation Water Demands (MGD) by Island under Three Macroeconomic Scenarios, Crops Excluding Pasture and Potential Bioenergy

| Island | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|
| *Most Likely Scenario* | | | | | | |
| Kauai | 30 | 34 | 37 | 39 | 42 | 45 |
| Oahu | 14 | 15 | 17 | 17 | 18 | 19 |
| Molokai | 5 | 7 | 9 | 10 | 11 | 13 |
| Maui | 134 | 139 | 145 | 147 | 149 | 152 |
| Big Island | 64 | 68 | 72 | 75 | 79 | 83 |
| **Total State** | **247** | **262** | **279** | **289** | **300** | **311** |
| *Optimistic Scenario* | | | | | | |
| Kauai | 31 | 35 | 40 | 44 | 49 | 53 |
| Oahu | 14 | 16 | 18 | 19 | 20 | 22 |
| Molokai | 5 | 8 | 11 | 13 | 16 | 18 |
| Maui | 134 | 142 | 151 | 156 | 162 | 168 |
| Big Island | 64 | 69 | 75 | 81 | 86 | 93 |
| **Total State** | **248** | **270** | **295** | **313** | **333** | **355** |
| *Pessimistic Scenario* | | | | | | |
| Kauai | 30 | 32 | 34 | 35 | 36 | 37 |
| Oahu | 14 | 15 | 15 | 16 | 16 | 16 |
| Molokai | 5 | 6 | 7 | 7 | 7 | 8 |
| Maui | 133 | 136 | 139 | 138 | 138 | 137 |
| Big Island | 63 | 66 | 69 | 71 | 73 | 75 |
| **Total State** | **245** | **255** | **264** | **267** | **269** | **273** |

### 6.5 Summary and Conclusions

Projections of irrigation water demand are a fairly straight forward multiplication of the projected acreages of agricultural crops developed in Section 5 by the irrigation water requirements (IRR) estimated in Section 3. Water demand is defined to be the farm-level irrigation water needed for crops to achieve non-deficit yields. The simple average of IRR by island and for the studied irrigation systems on each island was computed.

The irrigation system showing the highest growth is Kekaha, followed by Lower Hamakua, Waimea and Molokai. The lowest demand growth is projected for Waimanalo and East Kauai. If a system is rehabilitated, then demand is projected to grow faster.

Projections of irrigation water demand by island are more difficult to interpret. The assumption is that all crops will be irrigated, regardless of whether irrigation water is presently available. Oahu and Molokai are the islands with the smallest irrigation water demand and the Big Island and Maui have the largest irrigation water demand over the next 25 years. The projected growth in demand depended on the scenario used. Projections of water demand by island were done with and without considering pasture, which dominates demand and is most often not irrigated.

The projections are for the irrigation water needed at the farm level. Since water losses occur along the delivery system from source to farmgate, these numbers would need to be increased to account for conveyance efficiency. Conveyance efficiencies are specific to each irrigation system and were not estimated in this study.

# 7. OVERALL CONCLUSIONS AND RECOMMENDATIONS

This study has produced various outputs for the Hawaii agricultural water plan. These include:

- GIS maps for 10 studied irrigation systems, 11 previously unstudied irrigated areas, and potential wastewater reuse areas around sewage treatment plants
- estimates of irrigation water duties at the studied systems for selected crops
- scoring model to assess long-run agricultural potential of the studied systems, without and with proposed rehabilitation
- projected agricultural acreages to the year 2030 for the main Hawaiian islands and at the studied irrigation systems under different macroeconomic scenarios
- special assessment with acreage projections for potential bioenergy crops
- estimated irrigation water demands to 2030 for projected crop acres.

The study was carried out to provide a variety of methodologies, tools and projections to assist planners and regulators. Each of the major sections has a concluding section that provides a short overview of what was presented. This will not be repeated here. This section discusses some qualifications and other issues that have arisen during the conduct of the study.

Crop water duties were derived from a water budget model based on historical rainfall and evaporative demand, with some assumptions on cropping pattern and farming practices. These estimates are for planning and not a forecast of actual water use by an individual farmer at a specific place and time. They were computed with a consistent methodology so one can make relative comparisons among different crops, places, and seasons.

Future acreages were projected to 2030 for seven crop groups plus bioenergy crops. This categorization reflects the current crop mix and potential plant sources for energy generation.

Projected acres were multiplied by average water duties for the crops within a particular group. It is not possible to accurately forecast growth for individual crops over such a long time period. The experience of Hawaii agriculture over the last several decades suggests that entirely new crops will emerge by 2030, while some traditional crop enterprises will decline or even completely disappear. Water planning should be dynamic to accommodate such changes.

Irrigation water estimates computed from projected crop acreages represent plants' biological demands for additional water beyond natural rainfall. These are not forecasts of actual irrigation water use. The latter would depend on many factors including available water supplies, irrigation infrastructure, access to water and water rights, and irrigation costs. The future of Hawaii agriculture is not predetermined. Water projections were made for different scenarios and provide a plausible range of outcomes, from which public and private water managers can develop their own plans for the future.

Agricultural irrigation in Hawaii continues transitioning from its plantation origins toward serving a dynamic agglomeration of diversified farmers. Projected increases in crop water demand are based on irrigation water duties estimated at the farm level. The respective demands on available water resources will depend on the efficiency with which irrigation systems can deliver water from the source to farms. Water delivery efficiency rates will vary with irrigation infrastructure and its condition, cropping patterns and system management, among other factors. Field observation at the 10 studied systems found wide variation in irrigation capabilities and farming practices. However, most systems do not systematically measure water except (at best) in a few key location(s). Therefore, it is not possible to develop even ballpark estimates of water delivery efficiency. If the average delivery rate is something like 50%, then actual increases in water demand could be double that projected in this study.

Government rehabilitation of former plantation systems has been ongoing for the past decade, even longer in a few cases. Some irrigation systems still in operation are very dilapidated. Conditions could be even worse at the unstudied systems. Phase I of the agricultural water plan proposed specific improvements for selected systems. However, it's not clear that consistent standards were applied in making these recommendations. To meet the demands of Hawaii agriculture in the 21st century, rehabilitation may need to go beyond reconstruction of the original infrastructure. Irrigation management can no longer afford the large labor forces once employed by the plantations for system operation and maintenance. New technologies are available that would reduce labor requirements while improving water control and management's responsiveness to farmer demands. Upgrading irrigation capabilities should be considered for future rehabilitation projects.

Modernized infrastructure needs management systems to utilize new capabilities. The studied irrigation systems represent a management continuum from original plantation operations to government systems operated by civil service employees to hybrid public-private arrangements. The latter are prevalent at systems most recently turned over from plantation to diversified crops. Management innovations include sharing responsibilities with various farmer groups and/or outsourcing some system activities (e.g., maintenance, security) and even day-to-day operations. The emergent management systems should be monitored to determine long-run effectiveness in improving irrigation service and efficiency.

The decline of plantation agriculture in Hawaii is transforming rural areas. At some irrigation systems, there is currently little active farming and most lands have been idled. Agricultural lands are being subdivided. These may be sold to "gentlemen farmers," who build a new house but have no interest in commercial farming, or converted to non-farm uses (e.g., residential subdivisions, condos or visitor time-share units). Rural residents are now commuting to jobs in other areas, which has generated considerable traffic congestion on most islands. Unfortunately, there are no data to document the extent of land use changes and respective impacts on Hawaii's people.

Table 7.1 Estimated Cost of Studies Identified by Agencies for Future Agricultural Water Plan Updates

| Study Item and Description | Minimum Cost |
|---|---|
| *Ground Water Resources, Locations, and Potential Yields*<br>Inventory of the records from different agencies i.e., DLNR. Groundtruthing and field determination of potential yield for the locations that have missing records. Estimating the costs of rehabilitation and upgrading of the existing infrastructure of the existing systems (if any). | 400,000 |
| *Surface Water Sources, Locations, and Potential Yields*<br>Inventory of the records from different agencies i.e., DLNR. Groundtruthing and field determination of potential yield for the locations that have missing records. Estimating the costs of rehabilitation and upgrading of the existing infrastructure of the existing systems. | 400,000 |
| *Surface Water Diversions and Locations* Surveying the existing records to determine all diversion locations that are either active or were active in the past. Evaluating the status of the existing diversions. Assessing the needs to rehabilitate these diversions. Quantifying the potential delivery capacity of the existing systems. | 200,000 |
| *Previously Unstudied Systems* For 7 systems (11 irrigated areas):<br>- engineering review, preliminary design and cost estimates for capital improvements;<br>- estimation of crop water duties, assessment of agricultural potential, crop acreage projections. | 600,000<br><br>350,000 |
| *Hydroponics and Nursery Irrigation*<br>Inventory of hydroponic farms. Farm surveys on special circumstances in water sources, irrigation practices, costs, and water use. | 200,000 |
| *In-Depth Study of Biofuels*<br>1) Determining optimal locations for biofuel production based on major defining indicators i.e., available agricultural land and water resources,<br>2) Simulating different crop energy sources based on their energy yield and their demand on natural resources, and<br>3) Economic analysis of the different potential scenarios. | 350,000 |
| *Potential Use of Reclaimed Water*<br>Survey of current reclamation schemes including physical facilities, water service, costs. Engineering and statistical analyses. Identify barriers to expanding reclaimed water use, develop recommendations to overcome barriers. | 450,000 |
| *Connection with Important Agricultural Lands (IAL) Classification*<br>Review of state and county policies for IAL designation and criteria related to water. | 35,000 |

Reductions in sugar acreage have released lots of water that could be reallocated to other purposes. The projected water demands for agriculture in 2030 can probably be met on a statewide basis. However, the benefits and costs of expanding irrigation service areas beyond what presently exists will need to be assessed on a project by project basis. Shortages may appear in some locations like central Molokai. Prospects for bioenergy crops are still very uncertain. And it's not clear that bioenergy crops will be irrigated. If so, this could significantly raise agricultural demand for water.

Rehabilitation of existing irrigation systems may be necessary to meet rising demands for water. Hawaii's farmers compete in a global marketplace. It's doubtful that they can pay the entire cost of improvements to irrigation infrastructure. Some irrigation systems now provide water to non-agricultural users like golf courses. This can reduce demand pressures on potable water supplies and provide additional revenues for system operation and maintenance. Greater reuse of wastewater offers another opportunity to stretch natural supplies of water. The GIS analysis in this study did identify zones where wastewater might be used. But it did not consider the costs of new infrastructure and operational expenses (e.g., energy for pumping) to deliver reclaimed water to irrigable areas. This issue will need to be addressed in a later phase of the agricultural water plan.

The agencies that sponsored this study have already identified other topics for future updates of the agricultural water plan. At their request, our project team developed short descriptions and estimated costs for these items, shown in Table 7.1. The cost numbers are rough estimates of the minimum amount needed to address the topic in a meaningful way. They are not proposed research projects by our study team nor obligate the University of Hawaii to conduct such studies.

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# 9. APPENDICES

## Appendix 9.1: Land Cover/Land Use Classification for the Derivation of General Crop Type Maps

Land cover/land use maps were created for the service areas of the 10 irrigation systems by classifying fine-resolution Emerge and/or IKONOS remotely-sensed images (acquired in or after 2000). The images were first segmented and then all the segments were classified based on their colors and textures. Finally, ground surveys were conducted to identify the surface cover (land use) types for each of the classes.

A hierarchical class-labeling system was developed for properly labeling every class for the purposes of this study (Fig. 9.1.1). In this system, a service area was first divided into two largest categories: non-irrigable and irrigable. Then, the irrigable areas were classified into four land categories: grazing, cultivated, cultivable, and non-cultivable (LAND_CAT in Fig. 9.1.1). The first two land category classes, grazing and cultivated, were further divided into two and four land cover/land use types, respectively (LULC in Fig. 9.1.1). Crop types (SPECIES in Fig. 9.1.1) were identified for the areas classified as "crop LULC" wherever possible; otherwise, it was labeled "unknown." The last two classes in this hierarchical system (LULC and SPECIES) were not used for any further analyses because these would change rapidly.

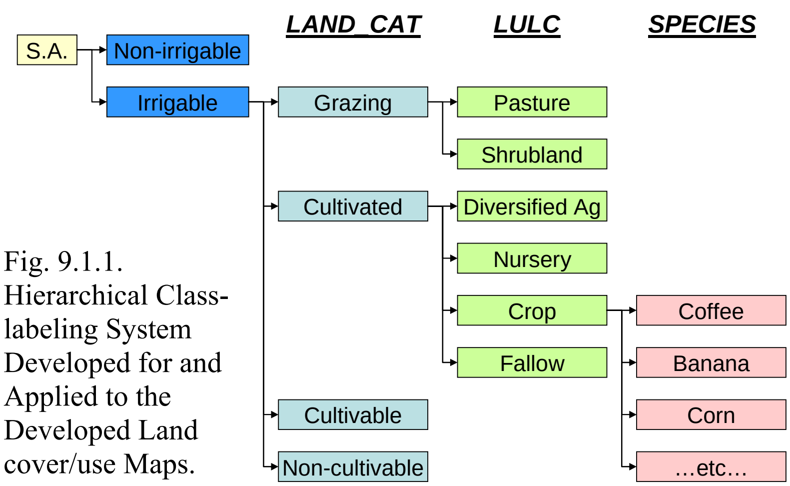


Fig. 9.1.1. Hierarchical Class-labeling System Developed for and Applied to the Developed Land cover/use Maps.

In practice, all non-irrigable areas were first identified and "erased" from the service areas. The segmentation processes were applied to these "erased" service areas. Distinctions between "shrubland" and "cultivable", and between "fallow" and "cultivable" were difficult for some areas. Hence, classification accuracy for these categories or classes could not be too high.

For the map generation purpose, five classes were used from the first two classification levels: (1) cultivated, (2) grazing, (3) cultivable, (4) non-cultivable, and (5) non-irrigable. "Non-irrigable" was defined as areas that are unlikely to be used for any agricultural activities, e.g., cliffs, gullies, rock outcrops, residential areas, etc. The other four classes were considered sub-categories of "Irrigable," or not "Non-irrigable." "Cultivable" were areas that were not currently used for any agricultural activities, including forested areas, rangelands (shrublands), and abandoned areas. If an area (or a segment) was not identified either "cultivated", "grazing", or "cultivable", it was classified as "non-cultivable."

Accuracy assessment was conducted to evaluate the performance and results of the classification algorithm. We evaluated for the Waiahole Ditch irrigation system in the Oahu island. For some service areas (e.g., the Kauai Coffee service area), accuracy assessment was not necessary because the superintendents were able to identify the current land uses for all the segments within the service areas. Classification accuracy, thus, should vary from a system to system and accuracy assessment results presented here should be taken as an example.

A random sample was generated over the service area and the actual land cover/land use types were identified at every sampling location via visual inspection on Earth Data images. Earth Data images were acquired in February and May of 2004 or May of 2005 at a flight altitude of 10,000 feet above mean terrain level (http://hawaii.wr.usgs.gov/oahu/earthdata.html). The images have a spatial resolution of 1 foot (30 cm) and, hence, many spatial features and objects were resolvable on the images (Fig. 9.1.2).

An overall accuracy of the classification results for this system was 77.2% (Table 9.1.1). The cultivable class had the lowest user accuracy of 62.5%, whereas the non-cultivable class had the lowest producer accuracy of 16.7%. The crop (unknown) class had the second lowest producer accuracy (47.1%), which was related to temporal accuracy. Some fields that were active when the Emerge and/or IKONOS images were acquired were inactive at the time of Earth Data image acquisitions.

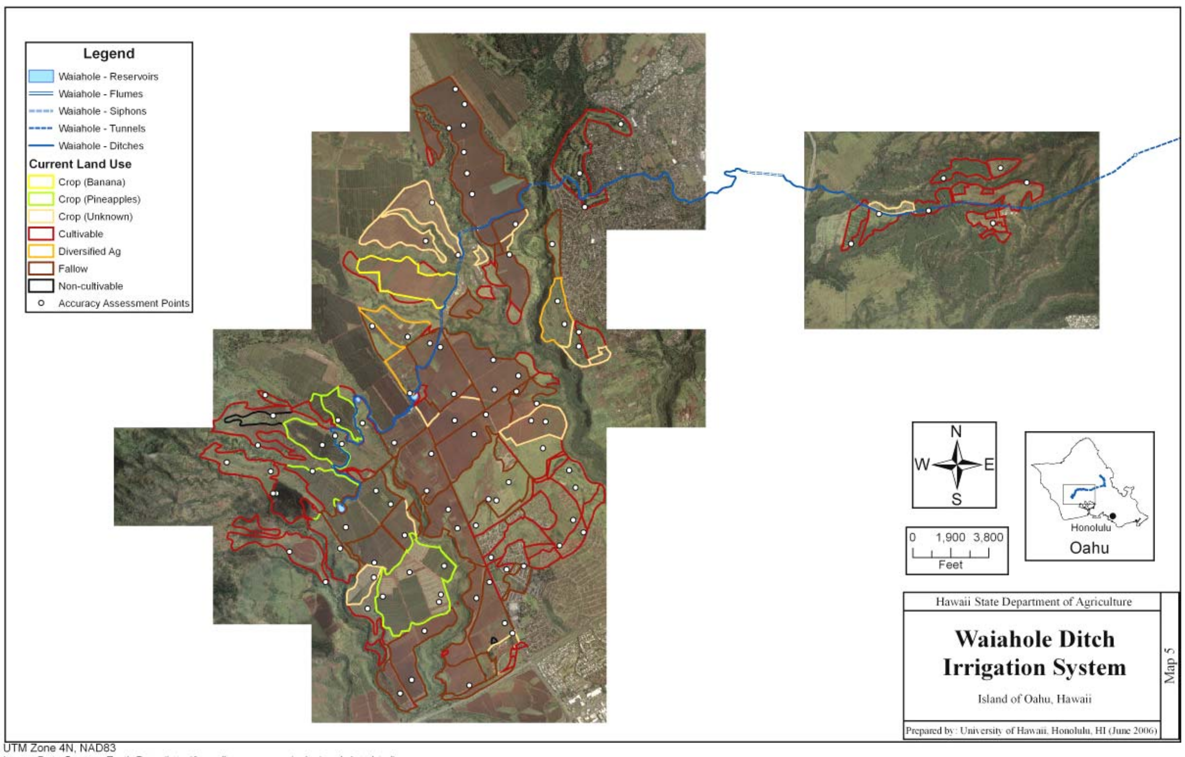


Fig. 9.1.2. Sampling Locations Randomly Generated for Accuracy Assessment.

Table 9.1.1. Error matrix for the Waiahole Ditch Irrigation System.

| | | Reference | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Crop(Ban) | Crop(Pine) | Crop(Unkn) | Cult | DivAg | Fallow | Non-cult | Total | User Acc |
| Classified | Crop(Ban) | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 100.0 |
| | Crop(Pine) | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 9 | 100.0 |
| | Crop(Unkn) | 0 | 0 | 8 | 0 | 0 | 3 | 0 | 11 | 72.7 |
| | Cult | 0 | 0 | 3 | 20 | 0 | 5 | 4 | 32 | 62.5 |
| | DivAg | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 4 | 100.0 |
| | Fallow | 0 | 0 | 6 | 1 | 0 | 33 | 1 | 41 | 80.5 |
| | Non-cult | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 100.0 |
| | Total | 3 | 9 | 17 | 21 | 4 | 41 | 6 | 101 | |
| | Producer Acc | 100.0 | 100.0 | 47.1 | 95.2 | 100.0 | 80.5 | 16.7 | Overall Acc | 77.2 |

## Appendix 9.2: Description of GIS Methods for the Generation of Projected Crop Acreage Maps

In depicting the projected crop acreages in map format, water delivery was assumed to be uniform throughout an entire irrigation system. In other words, water (amount) is equally available at any section of the irrigation system.

Two criteria of (1) land resource conditions and (2) spatial proximities to the irrigation systems (both laterally and elevationally) were used to spatially select locations within a service area where likely to be cultivated. These two criteria were equally-weighted. The areas that were identified as "cultivated" in land cover/use classification (Section 2.1.3) were excluded from the analysis.

For the assessment of land resource conditions, the Agricultural Land of Importance to State of Hawaii (ALISH) classification (Section 2.1.1) and irrigated and non-irrigated land capability class (LCC) classification (Section 2.1.2) were used. The following numerical scores were assigned to ALISH and LCC classes. The two factors were considered equally important and, thus, we multiplied these two GIS layers to obtain another layer that showed the ranking within a service area.

| ALISH Class | Score |
|---|---|
| Prime | 1.0 |
| Unique | 1.0 |
| Other | 0.5 |
| Unclassified | 0.0 |

| LCC Class | Score |
|---|---|
| I | 1.0 |
| II | 1.0 |
| III | 1.0 |
| IV | 1.0 |
| V | 0.5 |
| VI | 0.5 |
| VII | 0.5 |
| VIII | 0.0 |

Spatial proximity was quantified using USGS 10 m resolution digital elevation model (DEM). Using the irrigation line features (e.g., ditches, tunnels, flumes) as the source, the "cost distance" concept was applied to assign the cost of water delivery to every location within a service area from the nearest irrigation line features. Both lateral distances and elevational differences were computed from DEM and considered as the horizontal and vertical movement constraints, or cost, respectively.

The final GIS layer was derived as the product of the land resource and cost distance GIS layers.

**Appendix 9.3: Description of GIS Layer Creation Methods and Format for the 11 Irrigation Systems Identified in Chapter 3 of AWUDP 2004**

Two shapefiles were created for each island, one each of polygon and line shapefiles (Table 9.2.1). The shapefile labels describe island and shapefile type. For example, KauIrrLine is the Kauai line shapefile and KauIrrPoly is the Kauai polygon shapefile.

Table 9.2.1. Associations of Unstudied Irrigation Systems with GIS Layer Names.

| Name(s) of Ditches | Island | Database Name |
|---|---|---|
| Kaloko and Puu Ka Ele Ditches | Kauai | KauIrrLine / KauIrrPoly |
| Anahola Ditch | Kauai | KauIrrLine / KauIrrPoly |
| Upper and Lower Lihue Ditches and Waiahi-Illiiliula Ditch | Kauai | KauIrrLine / KauIrrPoly |
| Upper and Lower Haiku Ditches | Kauai | KauIrrLine / KauIrrPoly |
| Waiaha-Kuia Aqueduct, Waiahi-Iliiliula Ditch and Koloa-Wilcox Ditch | Kauai | KauIrrLine / KauIrrPoly |
| Olokele Ditch | Kauai | KauIrrLine / KauIrrPoly |
| Oahu Ditch | Oahu | OahIrrLine / OahIrrPoly |
| Opaeula, Kamananui, and Ito Ditches | Oahu | OahIrrLine / OahIrrPoly |
| Kau Agribusiness | Hawaii | HawIrrLine / HawIrrPoly |
| Kohala Ditch | Hawaii | HawIrrLine / HawIrrPoly |
| Kehana Ditch | Hawaii | HawIrrLine / HawIrrPoly |

We began with the USGS National Hydrography Dataset (NHD) (http://nhd.usgs.gov/). All fields from the NHD shapefiles were first deleted except OBJECTID, GNIS_Name, FCode, and Ftype. The following fields were then added:

| Field | Field Type | Property |
|---|---|---|
| SYSNAME | Text | 50 |
| SUBSYSNAME | Text | 50 |
| SYSFTRNAME | Text | 50 |
| SYSTYPE | Text | 15 |
| SYSTYPEID | Long Integer | NA |
| SYSSTATUS | Text | 10 |
| SYSSTATUSID | Long Integer | NA |
| SYSNOTE | Text | 100 |
| OWNER | Text | 50 |

**ATTRIBUTES** **DESCRIPTION/VALID VALUES**

SYSNAME: System Name

SUBSYSNAME: Ditch name

SYSFTRNAME: Describes smaller features within the ditch itself or the ditch system. For example, the name of the reservoir through which a reservoir path flows. In some cases, smaller ditches or ditches not related to an identified system might be labeled in this field.

SYSTYPEID/SYSTYPE/”FTYPE”/FCODE:

1 = Canal = “Canal/Ditch” used for drainage = 336--
2 = Ditch = “Canal/Ditch” used for irrigation = 336--
3 = Flume = “Flume” = 36200
4 = Penstock = “Pipeline: Pipeline Type = Penstock” = 42815
5 = Pipeline = “Pipeline” all types other than those specified elsewhere = 428--
6 = Siphon = Siphon = “Pipeline: Pipeline Type = Siphon” = 42813
7 = Tunnel = “Tunnel” = 47800
8 = ReservoirPath = “Artificial Path” flowing through a reservoir = 55800
9 = StreamPath = “Artificial Path” flowing through a stream channel = 55800

SYSSTATID/SYSSTATUS:

1 = Active = Currently operated, structurally sound, flowing water
2 = Inactive = Not in use. Abandoned, damaged, or not used. Explained in SYSNOTE
3 = Unknown = Unknown

OWNER: Determined by landowner as identified in Tax Map Keys (TMK)

Each island’s NHDFlowline layer was appended to the island’s NHDLine layer to obtain all of the following FTypes in a single layer: Ditch, Canal, Flume, Artificial Path (changed to ReservoirPath or StreamPath), Penstock, Pipeline, Siphon, and Tunnel. This step was necessary because Flume and Tunnel FTypes are found only in the NHDLine layer, and CanalDitch, Pipeline, StreamRiver, and Artificial Path FTypes are found only in the NHDFlowline layer.

The append resulted in many duplicate features. Tunnel and Flume FTypes were captured, in the same extent, also as CanalDitch. The Tunnel or Flume FType was assumed to be correct, and the duplicate CanalDitch portions were manually deleted.

Polygon layers were created from the NHDWaterbody feature class. All fields from the NHD shapefiles were deleted except OBJECTID, GNIS_Name, FCode, and Ftype. The following fields were added:

| Field | Field Type | Property |
|---|---|---:|
| SYSNAME | Text | 50 |
| SUBSYSNAME | Text | 50 |
| SYSFTRNAME | Text | 50 |
| SYSTYPE | Text | 15 |
| SYSTYPEID | Long Integer | NA |
| SYSSTATUS | Text | 10 |
| SYSSTATUSID | Long Integer | NA |
| SYSNOTE | Text | 100 |
| OWNER | Text | 50 |
| SUBTYPE | Text | 15 |
| SUBTYPEID | Long Integer | NA |

| ATTRIBUTES | DESCRIPTION/VALID VALUES |
|---|---|
| SYSNAME: | System Name |
| SUBSYSNAME: | Ditch name |
| SYSFTRNAME: | Feature name |

SYSTYPEID/SYSTYPE/FTYPE/FCODE:
1 = LakePond = “Lake/Pond” all types = 390--
2 = SwampMarsh = “Swamp/Marsh” = 46600
3 = Reservoir = “Reservoir” all types = 436--

SYSSTATID/SYSSTATUS:
1 = Active = Currently operated, structurally sound, flowing water
2 = Inactive = Not in use. Abandoned, damaged, or not used. Explained in SYSNOTES
3 = Unknown = Unknown

SYSNOTE: Other information not explained by other fields. For example, capacity or explanation of status.

OWNER: Determined by landowner as identified in TMK or DLNR Emergency Dam Inspection Report

SUBTYPEID/SUBTYPE:
1 = Natural
2 = Fishpond
3 = Agricultural
4 = Golf Course
5 = Hotel
6 = Municpal
7 = Residential
8 = Unknown

Polygon subtype for reservoirs within unstudied systems was assumed to be “Agricultural” unless otherwise noted in attribute information gathering process.

CWRM Declaration of Water Use Files provided information on feature name, owner, operator, users, system capacity, and status for select systems. Ditch operators were contacted by telephone for information on system capacity and status. Some reservoir capacity and ownership information was obtained from DLNR Visual Dam Safety Inspection Sheets available online. Data sources included:

- USGS Topographic maps
- CWRM Declaration of Water Use Files
- Ditch owners and operators
- TMK Stream Diversion GIS shapefile, public version
- DLNR, Visual Dam Safety Inspection Sheets, available at <http://www.hawaii.gov/dlnr/reports/dam-inspections/> (accessed: 2 December 2006).
- Wilcox, Carol (1996), *Sugar Water: Hawaii’s Plantation Ditches*, Honolulu: University of Hawaii Press.

Potential service areas of each of the 11 unstudied systems were derived based on (1) land ownerships (current or inherited from former sugarcane companies), (2) elevation (since most of the irrigation systems are gravity-fed), (3) current land use, and (4) historical spatial extent and distribution of sugarcane fields.

For each irrigation system, areas that were at lower elevation than ditch diversion locations (diversions to farm fields) were delineated using USGS 1:24,000 DEMs and topo quadrangles. Tax map keys (TMK) as of September 7, 2006 and State Land Use Districts as of April 20, 2006 obtained from Hawaii State GIS Program at the State of Hawaii's Office of Planning (http://www.hawaii.gov/dbedt/gis/) were then overlaid and used to erase developed, residential areas and to confirm active-agricultural areas. Additional information regarding the current agricultural activities on the former sugarcane lands were gathered by interviewing CTAHR extension specialists and personnel at CTAHR Soil Diagnostic Analysis Lab, and from published information available on the world wide web.

Finally, historical orthophotobases (USDA Soil Conservation Service, 1972, 1973) were used to assess the historical distribution and spatial extent of sugarcane fields and of ditches and to draw boundaries of the potential service areas at the lowest elevation. Many sugarcane companies were using both well water and diverted water to irrigate the sugarcane fields. We presumed, however, that most of the fields could be irrigated via ditch systems as far as ditch networks existed throughout those fields. The orthophotobases were photographed in 1965.

Appendix 9.4: Climate Stations and Characteristics of the 10 Studied Irrigation Systems

| | | | | | | | | --------------Rain--------- | | | --------------ET----------- | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **System** | **STATION** | **Map ID Number (Appendix A)** | **State Key Number** | **Island** | **Elevation (ft)** | **Latitude** | **Longitude** | **Years of record** | **Period** | **Annual mean (in)** | **Years of record** | **Period** | **Annual mean (in)** |
| Kekaha | Mana | 1 | 1026.0 | Kauai | 10 | 22.04 | -159.77 | 45 | 1950-1995 | 28.4 | 4 | 1962-83 | 60.3 |
| Kekaha | Kekaha | 2 | 944.0 | Kauai | 10 | 21.97 | -159.71 | 48 | 1950-1999 | 21.3 | 9 | 1960-83 | 58.9 |
| Kauai Coffee | Wahiawa | 3 | 930.0 | Kauai | 215 | 21.90 | -159.56 | 54 | 1950-2004 | 35.3 | 15 | 1960-83 | 67.2 |
| Kauai Coffee | McBryde Station (ET) | 4 | 986.1 | Kauai | 630 | 21.92 | -159.54 | 0 | -- | -- | 16 | 1960-83 | 62.5 |
| Kauai Coffee | Bydswood Station (rain) | 5 | 985 | Kauai | 720 | 21.93 | -159.54 | 50 | 1952-2004 | 59.2 | 0 | -- | -- |
| East Kauai | Lihue Variety Station | 6 | 1062.1 | Kauai | 340 | 22.03 | -159.39 | 36 | 1964-1999 | 73.5 | 11 | 1965-83 | 54.8 |
| Waiahole | Kunia Substation | 7 | 740.5 | Oahu | 285 | 21.39 | -158.03 | 10 | 1994-2005 | 20.8 | 9 | 1994-2005 | 57 |
| Waimanalo | Waimanalo Experiment Station | 8 | 795.1 | Oahu | 60 | 21.34 | -157.71 | 29 | 1970-2000 | 42.5 | 31 | 1970-2000 | 47.5 |
| Molokai | Kualapuu Res. (ET) | 9 | 531.1 | Molokai | 800 | 21.16 | -157.04 | 0 | -- | -- | 11 | 1970-1984 | 94.2 |
| Molokai | Kualapuu (rain) | 10 | 534.0 | Molokai | 870 | 21.16 | -157.04 | 26 | 1950-1977 | 33.8 | 0 | -- | -- |
| West Maui | Pohakea Bridge (Rain) | 11 | 307.2 | Maui | 165 | 20.82 | -156.51 | 40 | 1950-2004 | 19.4 | 0 | -- | -- |
| West Maui | Field 906 (ET) | 12 | 310.1 | Maui | 160 | 20.83 | -156.50 | 0 | -- | -- | 19 | 1962-83 | 77.7 |
| Upcountry | Kula Branch | 13 | 324.5 | Maui | 933 | 20.76 | -156.33 | 24 | 1979-2005 | 23.8 | 23 | 1979-2005 | 49.5 |
| Waimea | Lalaumilo Field Office | 14 | 191.1 | Hawaii | 2620 | 20.01 | -155.69 | 23 | 1981-2004 | 16.9 | 4 | 1976-84 | 51.4 |
| Lower Hamakua | Hamakua Makai | 15 | 221.3 | Hawaii | 750 | 20.05 | -155.38 | 0 | -- | -- | 15 | 1964-1982 | 63.7 |
| Lower Hamakua | Paauilo | 16 | 221.0 | Hawaii | 800 | 20.04 | -155.37 | 55 | 1950-2005 | 94.9 | 0 | -- | -- |

Appendix 9.5: Perennial Crop Effective Root Depth Kc Values by Month of the Year

| **Crop** | **Root depth** (in) | | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** | **Irrigation type** | **Irrigation efficiency** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Initial** | **Final** | | | | | | | | | | | | | | |
| Coffee | 24 | 48 | 0.85 | 0.85 | 0.85 | 0.9 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.9 | 0.9 | Micro spray (MS) | 0.8 |
| Dendrobium, pot | 8 | 8 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | MS; nursery sprinkler | 0.80, 0.20 |
| Draceana, pot | 8 | 8 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | MS; nursery sprinkler | 0.80, 0.20 |
| Eucalyptus closed canopy | 72 | 72 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | Micro spray | 0.8 |
| Eucalyptus young | 48 | 72 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | Micro spray | 0.8 |
| Guava | 30 | 60 | 8.0 | 0.9 | 1.0 | 1.0 | 9.0 | 0.8 | 0.8 | 0.9 | 1.0 | 1.0 | 9.0 | 8.5 | Micro spray | 0.8 |
| Heliconia | 24 | 48 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | Micro spray | 0.8 |
| Kikuyu grass | 24 | 48 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | Sprinkler | 0.75 |
| Leuceana (Old) | 72 | 72 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | Micro spray | 0.8 |
| Leuceana (Young | 48 | 72 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | Micro spray | 0.8 |
| Lychee | 30 | 60 | 0.95 | 1.0 | 1.0 | 1.0 | 0.95 | 0.9 | 0.9 | 0.85 | 0.8 | 0.8 | 0.9 | 0.9 | Micro spray | 0.8 |
| Macadamia nut | 30 | 60 | 0.85 | 0.85 | 0.85 | 0.9 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.9 | 0.9 | Micro spray | 0.8 |
| Ti | 24 | 48 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | Micro spray | 0.8 |

Appendix 9.6: South Kekaha (Kekaha station) Seasonal Irrigation Requirements for Selected Crops

| **Crop Type** | **Irrigation Season** | **Length** (day) | **Net Rainfall** (inch) | **Potential ET** (inch) | **Crop ET** (inch) | **Drainage** (inch) | **Runoff** (inch) | **Mean Irrigation Requirement** (inch) | **Maximum Irrigation Requirement** (inch) | **Minimum Irrigation Requirement** (inch) | **Mean Irrigation Requirement** (1000 gallons/acre) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alfalfa, initial | 11-15 TO 1-15 | 62 | 5.5 | 7.2 | 5.8 | 2.2 | 1.3 | 2.1 | 4.7 | 0.0 | 57 |
| Alfalfa, initial | 5-15 TO 7-15 | 62 | 0.8 | 11.9 | 9.5 | 0.1 | 0.0 | 7.7 | 9.2 | 4.1 | 209 |
| Alfalfa, ratoon | 11-15 TO 1-15 | 62 | 5.5 | 7.2 | 5.8 | 1.9 | 1.3 | 1.9 | 5.2 | 0.0 | 52 |
| Alfalfa, ratoon | 5-15 TO 7-15 | 62 | 0.8 | 11.9 | 9.4 | 0.0 | 0.0 | 8.5 | 9.2 | 5.2 | 231 |
| Banana, initial | 10- 1 TO 9-30 | 365 | 17.7 | 58.9 | 52.3 | 4.3 | 3.6 | 45.1 | 54.3 | 32.9 | 1225 |
| Banana, initial | 5- 1 TO 4-30 | 365 | 17.7 | 58.9 | 46.7 | 0.9 | 3.6 | 28.4 | 41.2 | 18.9 | 771 |
| Banana, ratoon | 10- 1 TO 9-30 | 365 | 17.7 | 58.9 | 51.2 | 3.5 | 3.6 | 35.7 | 44.0 | 25.6 | 969 |
| Banana, ratoon | 5- 1 TO 4-30 | 365 | 17.7 | 58.9 | 45.0 | 0.5 | 3.6 | 21.9 | 34.3 | 12.9 | 595 |
| Cabbage | 11- 1 TO 1-31 | 92 | 8.4 | 11.1 | 9.1 | 3.4 | 2.1 | 3.8 | 6.9 | 1.1 | 103 |
| Cabbage | 5- 1 TO 7-31 | 92 | 1.6 | 17.5 | 14.7 | 0.2 | 0.1 | 13.6 | 15.1 | 10.9 | 369 |
| Cantaloupe | 10-15 TO 2-15 | 124 | 10.7 | 15.7 | 11.5 | 4.1 | 2.6 | 4.8 | 8.5 | 1.9 | 130 |
| Cantaloupe | 4-15 TO 8-15 | 123 | 2.5 | 23.3 | 17.1 | 0.3 | 0.2 | 15.5 | 17.8 | 11.8 | 421 |
| Dry Onion | 10-15 TO 2-15 | 124 | 10.7 | 15.7 | 14.3 | 3.5 | 2.6 | 6.9 | 12.1 | 2.4 | 187 |
| Dry Onion | 4-15 TO 8-15 | 123 | 2.5 | 23.3 | 21.7 | 0.3 | 0.2 | 20.4 | 23.3 | 16.5 | 554 |
| Eggplant | 10-15 TO 2-15 | 124 | 10.7 | 15.7 | 13.2 | 3.8 | 2.6 | 6.1 | 10.3 | 2.3 | 166 |
| Eggplant | 4-15 TO 8-15 | 123 | 2.5 | 23.3 | 20.1 | 0.3 | 0.2 | 18.8 | 21.4 | 15.5 | 511 |
| Ginger (AWD Potatoes) | 10- 1 TO 9-30 | 365 | 17.7 | 58.9 | 55.5 | 4.4 | 3.6 | 46.8 | 55.3 | 37.6 | 1271 |
| Ginger (AWD Potatoes) | 5- 1 TO 4-30 | 365 | 17.7 | 58.9 | 54.1 | 3.2 | 3.6 | 44.8 | 56.7 | 35.5 | 1217 |
| Lettuce | 11-15 TO 1-15 | 62 | 5.5 | 7.2 | 5.7 | 2.7 | 1.3 | 3.2 | 5.4 | 0.7 | 87 |
| Lettuce | 5-15 TO 7-15 | 62 | 0.8 | 11.9 | 9.4 | 0.1 | 0.0 | 10 | 11.1 | 7.8 | 272 |
| Other Melon | 10-15 TO 2-15 | 124 | 10.7 | 15.7 | 13.2 | 3.8 | 2.6 | 6.1 | 10.5 | 2.7 | 166 |
| Other Melon | 4-15 TO 8-15 | 123 | 2.5 | 23.3 | 20.1 | 0.3 | 0.1 | 18.8 | 21.5 | 15.3 | 511 |
| Pineapple, year 1 | 10- 1 TO 9-30 | 365 | 17.7 | 58.9 | 23.6 | 5.2 | 3.6 | 9.5 | 14.5 | 4.5 | 258 |
| Pineapple, year 1 | 5- 1 TO 4-30 | 365 | 17.7 | 58.9 | 26.1 | 4.7 | 3.6 | 13.6 | 20.3 | 9.3 | 369 |
| Pineapple, year 2 | 10- 1 TO 9-30 | 365 | 17.7 | 58.9 | 24.9 | 4.4 | 3.6 | 10.3 | 16.6 | 4.5 | 280 |
| Pineapple, year 2 | 5- 1 TO 4-30 | 365 | 17.7 | 58.9 | 26.0 | 3.8 | 3.6 | 12.4 | 19.4 | 7.4 | 337 |
| Pumpkin | 10-15 TO 2-15 | 124 | 10.7 | 15.7 | 12.8 | 3.9 | 2.6 | 5.8 | 10.3 | 2.1 | 157 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Pumpkin | 4-15 TO 8-15 | 123 | 2.5 | 23.3 | 19.5 | 0.3 | 0.2 | 18.1 | 20.5 | 14.5 | 491 |
| Seed Corn | 10-15 TO 2-15 | 124 | 10.7 | 15.7 | 13.9 | 2.9 | 2.6 | 5.2 | 10.3 | 0.5 | 141 |
| Seed Corn | 4-15 TO 8-15 | 123 | 2.5 | 23.3 | 21.1 | 0.2 | 0.2 | 18.6 | 21.2 | 14.8 | 505 |
| Sugarcane, New- year 1 | 10- 1 TO 9-30 | 365 | 17.7 | 58.9 | 60.9 | 3.8 | 3.6 | 48.5 | 56.8 | 37.5 | 1317 |
| Sugarcane, New- year 1 | 5- 1 TO 4-30 | 365 | 17.7 | 58.9 | 54.4 | 0.6 | 3.6 | 37.6 | 51.6 | 24.7 | 1021 |
| Sugarcane, New- year 2 | 10- 1 TO 9-30 | 365 | 17.7 | 58.9 | 55.9 | 2.2 | 3.6 | 41.3 | 51.3 | 27.6 | 1121 |
| Sugarcane, New- year 2 | 5- 1 TO 4-30 | 365 | 17.7 | 58.9 | 54.2 | 0.8 | 3.6 | 38.9 | 52.9 | 28.0 | 1056 |
| Sugarcane, ratoon | 10- 1 TO 9-30 | 365 | 17.7 | 58.9 | 61.9 | 1.9 | 3.6 | 47.9 | 58.2 | 33.7 | 1301 |
| Sugarcane, ratoon | 5- 1 TO 4-30 | 365 | 17.7 | 58.9 | 59.5 | 0.5 | 3.6 | 44.5 | 58.2 | 32.3 | 1208 |
| Sweet potatoes | 10- 1 TO 2-28 | 151 | 12.0 | 19.8 | 18.1 | 3.2 | 2.8 | 9.4 | 14.9 | 3.3 | 255 |
| Sweet potatoes | 4- 1 TO 8-31 | 153 | 3.1 | 28.8 | 27.1 | 0.3 | 0.4 | 26.2 | 29.3 | 21.6 | 711 |
| Taro | 10- 1 TO 9-30 | 365 | 17.7 | 58.9 | 65.4 | 11.9 | 3.6 | 119.8 | 125.5 | 110.9 | 3253 |
| Taro | 5- 1 TO 4-30 | 365 | 17.7 | 58.9 | 64.6 | 11.8 | 3.6 | 117.9 | 125.8 | 108.0 | 3201 |
| Tomato | 10-15 TO 2-15 | 124 | 10.7 | 15.7 | 14.1 | 3.6 | 2.6 | 6.8 | 11.7 | 2.6 | 185 |
| Tomato | 4-15 TO 8-15 | 123 | 2.5 | 23.3 | 21.5 | 0.3 | 0.2 | 20.4 | 22.9 | 16.7 | 554 |
| Watermelon | 10-15 TO 2-15 | 124 | 10.7 | 15.7 | 13.1 | 3.8 | 2.6 | 6.1 | 10.4 | 2.5 | 166 |
| Watermelon | 4-15 TO 8-15 | 123 | 2.5 | 23.3 | 19.7 | 0.3 | 0.2 | 18.4 | 20.9 | 14.6 | 500 |
| Coffee | 1- 1 TO 12-31 | 365 | 17.9 | 58.9 | 54.5 | 2.1 | 3.6 | 48.3 | 61.3 | 33.7 | 1312 |
| Dendrobium, pot, micro-sprink | 1- 1 TO 12-31 | 365 | 17.9 | 58.9 | 59 | 7.3 | 3.6 | 60.6 | 68.7 | 50.4 | 1646 |
| Dendrobium, pot, nursery spray | 1- 1 TO 12-31 | 365 | 17.9 | 58.9 | 59 | 10.3 | 3.6 | 187.1 | 200.9 | 168.5 | 5081 |
| Draceana, pot micro-sprink | 1- 1 TO 12-31 | 365 | 17.9 | 58.9 | 59 | 7.1 | 3.6 | 60.5 | 69.4 | 51.4 | 1643 |
| Draceana, pot, nursery spray | 1- 1 TO 12-31 | 365 | 17.9 | 58.9 | 59 | 9.4 | 3.6 | 186 | 201.8 | 167 | 5051 |
| Eucaluptus closed canopy | 1- 1 TO 12-31 | 365 | 17.9 | 58.9 | 59.0 | 2.1 | 3.6 | 53.9 | 66.5 | 36.7 | 1464 |
| Eucalyptus young | 1- 1 TO 12-31 | 365 | 17.9 | 58.9 | 37.0 | 2.0 | 3.6 | 26.3 | 38.9 | 12.9 | 714 |
| Guava | 1- 1 TO 12-31 | 365 | 17.9 | 58.9 | 53.7 | 1.6 | 3.6 | 46.7 | 60.9 | 31.2 | 1268 |
| Heliconia | 1- 1 TO 12-31 | 365 | 17.9 | 58.9 | 59.0 | 1.8 | 3.6 | 53.6 | 68.2 | 38.4 | 1455 |
| Kikuyu Grass | 1- 1 TO 12-31 | 365 | 17.9 | 58.9 | 59.0 | 2.2 | 3.6 | 57.6 | 71.8 | 39.7 | 1564 |
| Lychee | 1- 1 TO 12-31 | 365 | 17.9 | 58.9 | 54.0 | 1.5 | 3.6 | 44 | 57.7 | 28.2 | 1195 |
| Macadamia nut | 1- 1 TO 12-31 | 365 | 17.9 | 58.9 | 54.5 | 1.5 | 3.6 | 44.8 | 57.6 | 30.5 | 1217 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ti | 1- 1 TO 12-31 | 365 | 17.9 | 58.9 | 59.0 | 1.8 | 3.6 | 50.4 | 64.1 | 36.1 | 1369 |

Appendix 9.7: North Kekaha (Mana station) Seasonal Irrigation Requirements for Selected Crops

| **Crop Type** | **Irrigation Season** | **Length** (day) | **Net Rainfall** (inch) | **Potential ET** (inch) | **Crop ET** (inch) | **Drainage** (inch) | **Runoff** (inch) | **Mean Irrigation Requirement** (inch) | **Maximum Irrigation Requirement** (inch) | **Minimum Irrigation Requirement** (inch) | **Mean Irrigation Requirement** (1000 gallons/acre) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alfalfa, initial | 11-15 TO 1-15 | 62 | 5.8 | 7.7 | 6.3 | 2.1 | 1.3 | 1.9 | 4.9 | 0.0 | 52 |
| Alfalfa, initial | 5-15 TO 7-15 | 62 | 1.2 | 12.0 | 9.6 | 0.1 | 0.1 | 8.3 | 10.1 | 4.1 | 225 |
| Alfalfa, ratoon | 11-15 TO 1-15 | 62 | 5.8 | 7.7 | 6.3 | 1.7 | 1.3 | 1.8 | 5.8 | 0.0 | 49 |
| Alfalfa, ratoon | 5-15 TO 7-15 | 62 | 1.2 | 12.0 | 9.5 | 0.1 | 0.1 | 7.9 | 10.2 | 4.0 | 215 |
| Banana, initial | 10- 1 TO 9-30 | 365 | 19.8 | 60.3 | 53.5 | 4.1 | 3.6 | 37.2 | 44.8 | 26.0 | 1010 |
| Banana, initial | 5- 1 TO 4-30 | 365 | 19.9 | 60.3 | 48.2 | 0.8 | 3.6 | 28.4 | 38.2 | 16.8 | 771 |
| Banana, ratoon | 10- 1 TO 9-30 | 365 | 19.8 | 60.3 | 52.5 | 3.3 | 3.6 | 35.6 | 42.7 | 24.5 | 967 |
| Banana, ratoon | 5- 1 TO 4-30 | 365 | 19.9 | 60.3 | 46.8 | 0.5 | 3.6 | 26.8 | 37.4 | 14.4 | 728 |
| Cabbage | 11- 1 TO 1-31 | 92 | 8.7 | 11.8 | 9.9 | 3.1 | 2.1 | 3.9 | 6.9 | 1.0 | 106 |
| Cabbage | 5- 1 TO 7-31 | 92 | 2.0 | 17.7 | 14.9 | 0.2 | 0.2 | 13.0 | 14.7 | 8.5 | 353 |
| Cantaloupe | 10-15 TO 2-15 | 124 | 11.1 | 16.6 | 12.3 | 3.9 | 2.5 | 4.9 | 8.7 | 1.7 | 133 |
| Cantaloupe | 4-15 TO 8-15 | 123 | 2.9 | 23.5 | 17.2 | 0.2 | 0.2 | 14.8 | 16.9 | 9.3 | 402 |
| Dry Onion | 10-15 TO 2-15 | 124 | 11.1 | 16.6 | 15.2 | 3.2 | 2.5 | 7.0 | 12.1 | 2.7 | 190 |
| Dry Onion | 4-15 TO 8-15 | 123 | 2.9 | 23.5 | 21.9 | 0.2 | 0.2 | 19.6 | 22.0 | 13.6 | 532 |
| Eggplant | 10-15 TO 2-15 | 124 | 11.1 | 16.6 | 14.0 | 3.5 | 2.5 | 6.1 | 10.5 | 2.5 | 166 |
| Eggplant | 4-15 TO 8-15 | 123 | 2.9 | 23.5 | 20.2 | 0.3 | 0.2 | 18.1 | 20.6 | 12.3 | 491 |
| Ginger (AWD Potatoes) | 10- 1 TO 9-30 | 365 | 19.8 | 60.3 | 56.7 | 4.2 | 3.6 | 45.7 | 54.3 | 34.0 | 1241 |
| Ginger (AWD Potatoes) | 5- 1 TO 4-30 | 365 | 19.9 | 60.3 | 55.4 | 3.0 | 3.6 | 43.2 | 51.9 | 32.6 | 1173 |
| Lettuce | 11-15 TO 1-15 | 62 | 5.8 | 7.7 | 6.2 | 2.6 | 1.3 | 3.4 | 6.1 | 1.0 | 92 |
| Lettuce | 5-15 TO 7-15 | 62 | 1.2 | 12.0 | 9.5 | 0.1 | 0.1 | 9.5 | 10.8 | 6.3 | 258 |
| Other Melon | 10-15 TO 2-15 | 124 | 11.1 | 16.6 | 14.0 | 3.5 | 2.5 | 6.2 | 10.7 | 2.6 | 168 |
| Other Melon | 4-15 TO 8-15 | 123 | 2.9 | 23.5 | 20.2 | 0.2 | 0.2 | 18.2 | 20.5 | 12.4 | 494 |
| Pineapple, year 1 | 10- 1 TO 9-30 | 365 | 19.8 | 60.3 | 25.0 | 5.1 | 3.6 | 8.5 | 13.3 | 2.1 | 231 |
| Pineapple, year 1 | 5- 1 TO 4-30 | 365 | 19.9 | 60.3 | 27.2 | 4.7 | 3.6 | 12.3 | 15.7 | 4.4 | 334 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Pineapple, year 2 | 10- 1 TO 9-30 | 365 | 19.8 | 60.3 | 26.3 | 4.2 | 3.6 | 9.1 | 14.5 | 3.1 | 247 |
| Pineapple, year 2 | 5- 1 TO 4-30 | 365 | 19.9 | 60.3 | 27.4 | 3.7 | 3.6 | 11.6 | 16.6 | 3.1 | 315 |
| Pumpkin | 10-15 TO 2-15 | 124 | 11.1 | 16.6 | 13.6 | 3.6 | 2.5 | 5.8 | 10.2 | 2.1 | 157 |
| Pumpkin | 4-15 TO 8-15 | 123 | 2.9 | 23.5 | 19.6 | 0.2 | 0.2 | 17.4 | 19.7 | 11.4 | 472 |
| Seed, Corn | 10-15 TO 2-15 | 124 | 11.1 | 16.6 | 14.8 | 2.5 | 2.5 | 5.5 | 10.4 | 0.0 | 149 |
| Seed, Corn | 4-15 TO 8-15 | 123 | 2.9 | 23.5 | 21.4 | 0.2 | 0.2 | 18.3 | 20.8 | 12.8 | 497 |
| Sugarcane, New- year 1 | 10- 1 TO 9-30 | 365 | 19.8 | 60.3 | 62.2 | 3.6 | 3.6 | 46.4 | 55.0 | 34.0 | 1260 |
| Sugarcane, New- year 1 | 5- 1 TO 4-30 | 365 | 19.9 | 60.3 | 56.3 | 0.6 | 3.6 | 36.7 | 47.7 | 23.8 | 997 |
| Sugarcane, New- year 2 | 10- 1 TO 9-30 | 365 | 19.8 | 60.3 | 57.4 | 1.9 | 3.6 | 39.5 | 49.1 | 24.0 | 1073 |
| Sugarcane, New- year 2 | 5- 1 TO 4-30 | 365 | 19.9 | 60.3 | 55.9 | 0.6 | 3.6 | 37.8 | 47.4 | 26.2 | 1026 |
| Sugarcane, ratoon | 10- 1 TO 9-30 | 365 | 19.8 | 60.3 | 63.4 | 1.6 | 3.6 | 46.2 | 57.3 | 29.6 | 1255 |
| Sugarcane, ratoon | 5- 1 TO 4-30 | 365 | 19.9 | 60.3 | 61.3 | 0.3 | 3.6 | 43.5 | 54.0 | 29.9 | 1181 |
| Sweet potatoes | 10- 1 TO 2-28 | 151 | 12.8 | 20.8 | 19.1 | 2.9 | 2.8 | 9.4 | 15.0 | 3.2 | 255 |
| Sweet potatoes | 4- 1 TO 8-31 | 153 | 3.9 | 29.0 | 27.4 | 0.3 | 0.3 | 25.4 | 28.5 | 20.1 | 690 |
| Taro | 10- 1 TO 9-30 | 365 | 19.8 | 60.3 | 66.8 | 12.8 | 3.6 | 120.0 | 126.0 | 109.0 | 3259 |
| Taro | 5- 1 TO 4-30 | 365 | 19.9 | 60.3 | 66.1 | 12.8 | 3.6 | 119.0 | 125.0 | 108.0 | 3231 |
| Tomato | 10-15 TO 2-15 | 124 | 11.1 | 16.6 | 15.0 | 3.1 | 2.5 | 6.7 | 12.0 | 2.4 | 182 |
| Tomato | 4-15 TO 8-15 | 123 | 2.9 | 23.5 | 21.7 | 0.2 | 0.2 | 19.7 | 22.1 | 13.6 | 535 |
| Watermelon | 10-15 TO 2-15 | 124 | 11.1 | 16.6 | 13.9 | 3.6 | 2.5 | 6.3 | 10.8 | 2.8 | 171 |
| Watermelon | 4-15 TO 8-15 | 123 | 2.9 | 23.5 | 19.9 | 0.2 | 0.2 | 17.8 | 20.3 | 12.2 | 483 |
| Coffee | 1- 1 TO 12-31 | 365 | 20.0 | 60.3 | 55.8 | 1.8 | 3.6 | 46.9 | 58.5 | 30.9 | 1274 |
| Dendrobium, pot, micro-sprink | 1- 1 TO 12-31 | 365 | 20 | 60.3 | 60.3 | 7.8 | 3.6 | 60.1 | 67 | 47.5 | 1632 |
| Dendrobium, pot, nursery spray | 1- 1 TO 12-31 | 365 | 20 | 60.3 | 60.3 | 11.1 | 3.6 | 189 | 200 | 169 | 5132 |
| Draceana, pot micro-sprink | 1- 1 TO 12-31 | 365 | 20 | 60.3 | 60.3 | 7.6 | 3.6 | 59.8 | 66.6 | 47.4 | 1624 |
| Draceana, pot, nursery spray | 1- 1 TO 12-31 | 365 | 20 | 60.3 | 60.3 | 10.1 | 3.6 | 187 | 200 | 165 | 5078 |
| Eucaluptus closed canopy | 1- 1 TO 12-31 | 365 | 20.0 | 60.3 | 60.3 | 2.0 | 3.6 | 52.7 | 66.9 | 36.2 | 1431 |
| Eucalyptus young | 1- 1 TO 12-31 | 365 | 20.0 | 60.3 | 38.2 | 1.7 | 3.6 | 24.9 | 35.5 | 11.1 | 676 |
| Guava | 1- 1 TO 12-31 | 365 | 20.0 | 60.3 | 55.0 | 1.2 | 3.6 | 45.2 | 57.5 | 28.8 | 1227 |
| Heliconia | 1- 1 TO 12-31 | 365 | 20.0 | 60.3 | 60.3 | 1.5 | 3.6 | 52.3 | 64.7 | 35.3 | 1420 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Kikuyu Grass | 1- 1 TO 12-31 | 365 | 20.0 | 60.3 | 60.3 | 1.8 | 3.6 | 56.1 | 69.7 | 38.6 | 1523 |
| Lychee | 1- 1 TO 12-31 | 365 | 20.0 | 60.3 | 55.2 | 1.2 | 3.6 | 45.4 | 57.6 | 29.2 | 1233 |
| Macadamia nut | 1- 1 TO 12-31 | 365 | 20.0 | 60.3 | 55.8 | 1.2 | 3.6 | 46.2 | 58.4 | 29.0 | 1255 |
| Ti | 1- 1 TO 12-31 | 365 | 20.0 | 60.3 | 60.3 | 1.5 | 3.6 | 52.2 | 64.4 | 35.5 | 1417 |

Appendix 9.8: Lower Kauai Coffee (Wahiawa station) Seasonal Irrigation Requirements for Selected Crops

| **Crop Type** | **Irrigation Season** | **Length** (day) | **Net Rainfall** (inch) | **Potential ET** (inch) | **Crop ET** (inch) | **Drainage** (inch) | **Runoff** (inch) | **Mean Irrigation Requirement** (inch) | **Maximum Irrigation Requirement** (inch) | **Minimum Irrigation Requirement** (inch) | **Mean Irrigation Requirement** (1000 gallons/acre) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alfalfa, initial | 11-15 TO 1-15 | 62 | 7.1 | 8.9 | 7.4 | 1.8 | 1.9 | 1.2 | 4.9 | 0.0 | 33 |
| Alfalfa, initial | 5-15 TO 7-15 | 62 | 3.3 | 13.3 | 10.9 | 0.1 | 0.1 | 6.7 | 10.0 | 0.0 | 182 |
| Alfalfa, ratoon | 11-15 TO 1-15 | 62 | 7.1 | 8.9 | 7.4 | 1.4 | 1.9 | 1.0 | 4.9 | 0.0 | 27 |
| Alfalfa, ratoon | 5-15 TO 7-15 | 62 | 3.3 | 13.3 | 10.8 | 0.0 | 0.1 | 6.6 | 10.0 | 0.0 | 179 |
| Banana, initial | 10- 1 TO 9-30 | 365 | 29.8 | 67.6 | 61.1 | 3.9 | 5.2 | 32.0 | 44.7 | 23.7 | 869 |
| Banana, initial | 5- 1 TO 4-30 | 365 | 29.7 | 67.6 | 56.0 | 0.3 | 5.2 | 24.6 | 37.8 | 10.1 | 668 |
| Banana, ratoon | 10- 1 TO 9-30 | 365 | 29.8 | 67.6 | 60.0 | 3.1 | 5.2 | 30.5 | 43.3 | 21.5 | 828 |
| Banana, ratoon | 5- 1 TO 4-30 | 365 | 29.7 | 67.6 | 54.9 | 0.1 | 5.2 | 23.4 | 36.3 | 8.1 | 635 |
| Cabbage | 11- 1 TO 1-31 | 92 | 10.7 | 13.6 | 11.6 | 2.8 | 2.9 | 3.0 | 6.6 | 0.8 | 81 |
| Cabbage | 5- 1 TO 7-31 | 92 | 5.2 | 19.7 | 16.7 | 0.3 | 0.3 | 10.7 | 14.0 | 5.0 | 291 |
| Cantaloupe | 10-15 TO 2-15 | 124 | 13.6 | 19.0 | 14.4 | 3.6 | 3.6 | 3.8 | 7.6 | 1.5 | 103 |
| Cantaloupe | 4-15 TO 8-15 | 123 | 7.3 | 26.1 | 19.5 | 0.4 | 0.5 | 11.9 | 16.1 | 5.8 | 323 |
| Dry Onion | 10-15 TO 2-15 | 124 | 13.6 | 19.0 | 17.5 | 2.6 | 3.6 | 5.9 | 10.5 | 2.0 | 160 |
| Dry Onion | 4-15 TO 8-15 | 123 | 7.3 | 26.1 | 24.5 | 0.4 | 0.5 | 16.8 | 20.9 | 10.6 | 456 |
| Eggplant | 10-15 TO 2-15 | 124 | 13.6 | 19.0 | 16.3 | 3.1 | 3.6 | 5.2 | 9.7 | 1.8 | 141 |
| Eggplant | 4-15 TO 8-15 | 123 | 7.3 | 26.1 | 22.7 | 0.4 | 0.5 | 15.3 | 19.9 | 8.7 | 415 |
| Ginger (AWD Potatoes) | 10- 1 TO 9-30 | 365 | 29.8 | 67.6 | 63.7 | 3.9 | 5.2 | 39.6 | 51.7 | 30.1 | 1075 |
| Ginger (AWD Potatoes) | 5- 1 TO 4-30 | 365 | 29.7 | 67.6 | 62.4 | 2.2 | 5.2 | 38.6 | 52.5 | 25.3 | 1048 |
| Lettuce | 11-15 TO 1-15 | 62 | 7.1 | 8.9 | 7.3 | 2.4 | 1.9 | 2.6 | 5.6 | 0.5 | 71 |
| Lettuce | 5-15 TO 7-15 | 62 | 3.3 | 13.3 | 10.6 | 0.1 | 0.1 | 7.9 | 10.8 | 2.3 | 215 |
| Other Melon | 10-15 TO 2-15 | 124 | 13.6 | 19.0 | 16.3 | 3.1 | 3.6 | 5.2 | 10.0 | 2.0 | 141 |
| Other Melon | 4-15 TO 8-15 | 123 | 7.3 | 26.1 | 22.6 | 0.4 | 0.5 | 15.1 | 20.0 | 8.4 | 410 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Pineapple, year 1 | 10- 1 TO 9-30 | 365 | 29.8 | 67.6 | 31.2 | 5.5 | 5.2 | 4.7 | 10.6 | 0.7 | 128 |
| Pineapple, year 1 | 5- 1 TO 4-30 | 365 | 29.7 | 67.6 | 33.4 | 5.6 | 5.2 | 9.5 | 15.8 | 4.4 | 258 |
| Pineapple, year 2 | 10- 1 TO 9-30 | 365 | 29.8 | 67.6 | 33.3 | 4.4 | 5.2 | 6.0 | 14.3 | 1.3 | 163 |
| Pineapple, year 2 | 5- 1 TO 4-30 | 365 | 29.7 | 67.6 | 34.7 | 4.0 | 5.2 | 9.5 | 15.7 | 4.0 | 258 |
| Pumpkin | 10-15 TO 2-15 | 124 | 13.6 | 19.0 | 15.9 | 3.2 | 3.6 | 4.8 | 9.6 | 1.7 | 130 |
| Pumpkin | 4-15 TO 8-15 | 123 | 7.3 | 26.1 | 22.0 | 0.4 | 0.5 | 14.5 | 18.9 | 7.9 | 394 |
| Seed, Corn | 10-15 TO 2-15 | 124 | 13.6 | 19.0 | 17.3 | 2.0 | 3.6 | 4.5 | 9.5 | 0.8 | 122 |
| Seed, Corn | 4-15 TO 8-15 | 123 | 7.3 | 26.1 | 24.2 | 0.3 | 0.5 | 15.9 | 20.7 | 9.0 | 432 |
| Sugarcane, New- year 1 | 10- 1 TO 9-30 | 365 | 29.8 | 67.6 | 70.6 | 3.3 | 5.2 | 42.6 | 55.4 | 31.9 | 1157 |
| Sugarcane, New- year 1 | 5- 1 TO 4-30 | 365 | 29.7 | 67.6 | 64.9 | 0.3 | 5.2 | 33.6 | 46.4 | 17.8 | 912 |
| Sugarcane, New- year 2 | 10- 1 TO 9-30 | 365 | 29.8 | 67.6 | 65.2 | 1.6 | 5.2 | 35.5 | 50.5 | 23.4 | 964 |
| Sugarcane, New- year 2 | 5- 1 TO 4-30 | 365 | 29.7 | 67.6 | 64.1 | 0.2 | 5.2 | 34.7 | 47.6 | 19.1 | 942 |
| Sugarcane, ratoon | 10- 1 TO 9-30 | 365 | 29.8 | 67.6 | 71.8 | 1.3 | 5.2 | 42.7 | 58.5 | 30.0 | 1159 |
| Sugarcane, ratoon | 5- 1 TO 4-30 | 365 | 29.7 | 67.6 | 69.9 | 0.1 | 5.2 | 40.8 | 54.1 | 24.0 | 1108 |
| Sweet potatoes | 10- 1 TO 2-28 | 151 | 16.0 | 23.8 | 22.2 | 2.3 | 4.0 | 8.3 | 15.3 | 2.2 | 225 |
| Sweet potatoes | 4- 1 TO 8-31 | 153 | 9.3 | 32.2 | 30.9 | 0.6 | 0.6 | 22.8 | 28.5 | 16.4 | 619 |
| Taro | 10- 1 TO 9-30 | 365 | 29.8 | 67.6 | 75.0 | 16.0 | 5.2 | 123.0 | 133.0 | 115.0 | 3340 |
| Taro | 5- 1 TO 4-30 | 365 | 29.7 | 67.6 | 74.2 | 15.9 | 5.2 | 121.0 | 132.0 | 111.0 | 3286 |
| Tomato | 10-15 TO 2-15 | 124 | 13.6 | 19.0 | 17.4 | 2.8 | 3.6 | 5.8 | 11.0 | 1.8 | 157 |
| Tomato | 4-15 TO 8-15 | 123 | 7.3 | 26.1 | 24.3 | 0.4 | 0.5 | 17.0 | 21.8 | 10.6 | 462 |
| Watermelon | 10-15 TO 2-15 | 124 | 13.6 | 19.0 | 16.1 | 3.1 | 3.5 | 5.1 | 9.5 | 2.1 | 138 |
| Watermelon | 4-15 TO 8-15 | 123 | 7.3 | 26.1 | 22.2 | 0.4 | 0.5 | 14.7 | 19.3 | 8.2 | 399 |
| Coffee | 1- 1 TO 12-31 | 365 | 30.1 | 67.6 | 62.7 | 1.1 | 5.2 | 42.3 | 55.1 | 26.7 | 1149 |
| Dendrobium, pot, micro-sprink | 1- 1 TO 12-31 | 365 | 30.1 | 67.6 | 67.7 | 8.1 | 5.2 | 57.1 | 68 | 46.5 | 1551 |
| Dendrobium, pot, nursery spray | 1- 1 TO 12-31 | 365 | 30.1 | 67.6 | 67.7 | 13.4 | 5.2 | 198 | 211 | 181 | 5377 |
| Draceana, pot micro-sprink | 1- 1 TO 12-31 | 365 | 30.1 | 67.6 | 67.7 | 7.7 | 5.2 | 56.5 | 65.5 | 47.3 | 1534 |
| Draceana, pot, nursery spray | 1- 1 TO 12-31 | 365 | 30.1 | 67.6 | 67.7 | 12.1 | 5.2 | 197 | 211 | 178 | 5349 |
| Eucaluptus closed canopy | 1- 1 TO 12-31 | 365 | 30.1 | 67.6 | 67.7 | 1.5 | 5.2 | 48.8 | 62.5 | 31.2 | 1325 |
| Eucalyptus young | 1- 1 TO 12-31 | 365 | 30.1 | 67.6 | 44.0 | 1.5 | 5.2 | 19.3 | 30.3 | 9.1 | 524 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Guava | 1- 1 TO 12-31 | 365 | 30.1 | 67.6 | 61.9 | 0.5 | 5.2 | 40.5 | 54.5 | 23.7 | 1100 |
| Heliconia | 1- 1 TO 12-31 | 365 | 30.1 | 67.6 | 67.7 | 0.7 | 5.2 | 47.9 | 62.1 | 30.5 | 1301 |
| Kikuyu Grass | 1- 1 TO 12-31 | 365 | 30.1 | 67.6 | 67.7 | 1.0 | 5.2 | 51.5 | 64.6 | 35.0 | 1398 |
| Lychee | 1- 1 TO 12-31 | 365 | 30.1 | 67.6 | 62.2 | 0.5 | 5.2 | 40.7 | 53.3 | 23.8 | 1105 |
| Macadamia nut | 1- 1 TO 12-31 | 365 | 30.1 | 67.6 | 62.7 | 0.5 | 5.2 | 41.5 | 54.6 | 25.6 | 1127 |
| Ti | 1- 1 TO 12-31 | 365 | 30.1 | 67.6 | 67.7 | 0.7 | 5.2 | 47.8 | 61.9 | 30.5 | 1298 |

Appendix 9.9: Upper Kauai Coffee (Brydswood and McBryde stations) Seasonal Irrigation Requirements for Selected Crops

| **Crop Type** | **Irrigation Season** | **Length** (day) | **Net Rainfall** (inch) | **Potential ET** (inch) | **Crop ET** (inch) | **Drainage** (inch) | **Runoff** (inch) | **Mean Irrigation Requirement** (inch) | **Maximum Irrigation Requirement** (inch) | **Minimum Irrigation Requirement** (inch) | **Mean Irrigation Requirement** (1000 gallons/acre) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alfalfa, initial | 11-15 TO 1-15 | 62 | 10.6 | 7.8 | 6.7 | 4.9 | 3.1 | 0.5 | 5.1 | 0.0 | 14 |
| Alfalfa, initial | 5-15 TO 7-15 | 62 | 7.2 | 12.9 | 10.8 | 0.6 | 0.4 | 3.2 | 7.2 | 0.0 | 87 |
| Alfalfa, ratoon | 11-15 TO 1-15 | 62 | 10.6 | 7.8 | 6.7 | 4.5 | 3.1 | 0.4 | 3.7 | 0.0 | 11 |
| Alfalfa, ratoon | 5-15 TO 7-15 | 62 | 7.2 | 12.9 | 10.8 | 0.4 | 0.4 | 3.0 | 7.4 | 0.0 | 81 |
| Banana, initial | 10- 1 TO 9-30 | 365 | 50.1 | 62.5 | 57.9 | 12.3 | 9.1 | 17.5 | 27.9 | 8.5 | 475 |
| Banana, initial | 5- 1 TO 4-30 | 365 | 49.9 | 62.5 | 53.4 | 6.5 | 9.1 | 9.0 | 25.4 | 1.2 | 244 |
| Banana, ratoon | 10- 1 TO 9-30 | 365 | 50.1 | 62.5 | 56.9 | 11.6 | 9.1 | 16.1 | 26.4 | 7.3 | 437 |
| Banana, ratoon | 5- 1 TO 4-30 | 365 | 49.9 | 62.5 | 52.6 | 5.9 | 9.1 | 8.0 | 23.2 | 1.2 | 217 |
| Cabbage | 11- 1 TO 1-31 | 92 | 15.8 | 12.0 | 10.5 | 7.2 | 4.7 | 1.6 | 5.7 | 0.0 | 43 |
| Cabbage | 5- 1 TO 7-31 | 92 | 10.7 | 19.0 | 16.5 | 1.0 | 0.8 | 6.1 | 9.8 | 1.4 | 166 |
| Cantaloupe | 10-15 TO 2-15 | 124 | 20.1 | 16.8 | 13.1 | 9.1 | 5.6 | 1.9 | 6.1 | 0.5 | 52 |
| Cantaloupe | 4-15 TO 8-15 | 123 | 15.1 | 25.1 | 19.6 | 1.9 | 1.4 | 6.1 | 9.9 | 1.8 | 166 |
| Dry Onion | 10-15 TO 2-15 | 124 | 20.1 | 16.8 | 15.7 | 7.7 | 5.6 | 3.0 | 8.7 | 0.9 | 81 |
| Dry Onion | 4-15 TO 8-15 | 123 | 15.1 | 25.1 | 23.9 | 1.5 | 1.4 | 9.9 | 14.6 | 3.7 | 269 |
| Eggplant | 10-15 TO 2-15 | 124 | 20.1 | 16.8 | 14.8 | 8.4 | 5.6 | 2.7 | 7.6 | 0.7 | 73 |
| Eggplant | 4-15 TO 8-15 | 123 | 15.1 | 25.1 | 22.4 | 1.8 | 1.4 | 8.7 | 13.3 | 2.4 | 236 |
| Ginger (AWD Potatoes) | 10- 1 TO 9-30 | 365 | 50.1 | 62.5 | 59.6 | 12.0 | 9.1 | 22.2 | 32.7 | 13.7 | 603 |
| Ginger (AWD Potatoes) | 5- 1 TO 4-30 | 365 | 49.9 | 62.5 | 58.3 | 10.1 | 9.1 | 20.9 | 35.7 | 10.9 | 568 |
| Lettuce | 11-15 TO 1-15 | 62 | 10.6 | 7.8 | 6.5 | 5.5 | 3.1 | 1.5 | 5.3 | 0.0 | 41 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Lettuce | 5-15 TO 7-15 | 62 | 7.2 | 12.9 | 10.7 | 0.8 | 0.4 | 4.5 | 8.7 | 0.4 | 122 |
| Other Melon | 10-15 TO 2-15 | 124 | 20.1 | 16.8 | 14.7 | 8.4 | 5.6 | 2.7 | 7.6 | 0.6 | 73 |
| Other Melon | 4-15 TO 8-15 | 123 | 15.1 | 25.1 | 22.3 | 1.8 | 0.8 | 8.6 | 13.1 | 2.5 | 234 |
| Pineapple, year 1 | 10- 1 TO 9-30 | 365 | 50.1 | 62.5 | 33.5 | 17.5 | 9.1 | 0.6 | 2.9 | 0.0 | 16 |
| Pineapple, year 1 | 5- 1 TO 4-30 | 365 | 49.9 | 62.5 | 35.8 | 17.4 | 9.1 | 3.7 | 8.4 | 0.0 | 100 |
| Pineapple, year 2 | 10- 1 TO 9-30 | 365 | 50.1 | 62.5 | 35.7 | 15.8 | 9.1 | 1.2 | 3.9 | 0.0 | 33 |
| Pineapple, year 2 | 5- 1 TO 4-30 | 365 | 49.9 | 62.5 | 36.9 | 15.4 | 9.1 | 3.1 | 7.9 | 0.0 | 84 |
| Pumpkin | 10-15 TO 2-15 | 124 | 20.1 | 16.8 | 14.3 | 8.5 | 5.6 | 2.5 | 7.7 | 0.2 | 68 |
| Pumpkin | 4-15 TO 8-15 | 123 | 15.1 | 25.1 | 21.7 | 1.8 | 1.4 | 8.1 | 12.6 | 2.3 | 220 |
| Seed, Corn | 10-15 TO 2-15 | 124 | 20.1 | 16.8 | 15.6 | 6.9 | 5.6 | 1.8 | 7.3 | 0.0 | 49 |
| Seed, Corn | 4-15 TO 8-15 | 123 | 15.1 | 25.1 | 23.9 | 1.3 | 1.4 | 9.5 | 13.9 | 1.1 | 258 |
| Sugarcane, New- year 1 | 10- 1 TO 9-30 | 365 | 50.1 | 62.5 | 66.5 | 11.0 | 9.1 | 26.1 | 38.1 | 14.4 | 709 |
| Sugarcane, New- year 1 | 5- 1 TO 4-30 | 365 | 49.9 | 62.5 | 61.2 | 3.8 | 9.1 | 13.0 | 30.9 | 0.0 | 353 |
| Sugarcane, New- year 2 | 10- 1 TO 9-30 | 365 | 50.0 | 62.5 | 61.1 | 8.2 | 9.1 | 18.2 | 30.6 | 6.2 | 494 |
| Sugarcane, New- year 2 | 5- 1 TO 4-30 | 365 | 49.9 | 62.5 | 60.3 | 5.3 | 9.1 | 16.6 | 33.4 | 6.4 | 451 |
| Sugarcane, ratoon | 10- 1 TO 9-30 | 365 | 50.1 | 62.5 | 67.1 | 7.4 | 9.1 | 23.8 | 37.3 | 11.2 | 646 |
| Sugarcane, ratoon | 5- 1 TO 4-30 | 365 | 49.9 | 62.5 | 65.2 | 4.0 | 9.1 | 20.5 | 39.8 | 8.0 | 557 |
| Sweet potatoes | 10- 1 TO 2-28 | 151 | 23.8 | 21.1 | 20.0 | 7.8 | 6.4 | 3.8 | 11.5 | 0.0 | 103 |
| Sweet potatoes | 4- 1 TO 8-31 | 153 | 18.7 | 30.8 | 30.0 | 2.2 | 1.7 | 13.8 | 19.8 | 6.0 | 375 |
| Taro | 10- 1 TO 9-30 | 365 | 50.1 | 62.5 | 69.4 | 29.8 | 9.1 | 98.7 | 108.4 | 89.9 | 2680 |
| Taro | 5- 1 TO 4-30 | 365 | 49.9 | 62.5 | 68.5 | 29.7 | 9.1 | 97.1 | 107.5 | 87.8 | 2637 |
| Tomato | 10-15 TO 2-15 | 124 | 20.1 | 16.8 | 15.7 | 7.8 | 5.6 | 3.0 | 9.3 | 0.3 | 81 |
| Tomato | 4-15 TO 8-15 | 123 | 15.1 | 25.1 | 23.9 | 1.7 | 1.4 | 10.1 | 14.6 | 3.4 | 274 |
| Watermelon | 10-15 TO 2-15 | 124 | 20.1 | 16.8 | 14.5 | 8.4 | 5.6 | 2.6 | 7.5 | 0.4 | 71 |
| Watermelon | 4-15 TO 8-15 | 123 | 15.1 | 25.1 | 21.9 | 1.8 | 1.4 | 8.1 | 12.7 | 2.6 | 220 |
| Coffee | 1- 1 TO 12-31 | 365 | 50.4 | 62.5 | 58.5 | 8.3 | 9.1 | 20.6 | 31.5 | 8.8 | 559 |
| Dendrobium, pot, micro-sprink | 1- 1 TO 12-31 | 365 | 50.4 | 62.5 | 62.6 | 17.2 | 9.1 | 36.7 | 44.8 | 29.5 | 997 |
| Dendrobium, pot, nursery spray | 1- 1 TO 12-31 | 365 | 50.4 | 62.5 | 62.6 | 25.3 | 9.1 | 158.0 | 174.0 | 138.0 | 4290 |
| Draceana, pot micro-sprink | 1- 1 TO 12-31 | 365 | 50.4 | 62.5 | 62.6 | 16.9 | 9.1 | 36.3 | 36.5 | 45.1 | 986 |
| Draceana, pot, nursery spray | 1- 1 TO 12-31 | 365 | 50.4 | 62.5 | 62.6 | 23.1 | 9.1 | 155.0 | 154.0 | 173.0 | 4209 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Eucaluptus closed canopy | 1- 1 TO 12-31 | 365 | 50.4 | 62.5 | 62.6 | 7.1 | 9.1 | 24.2 | 38.3 | 10.1 | 657 |
| Eucalyptus young | 1- 1 TO 12-31 | 365 | 50.4 | 62.5 | 43.2 | 11.3 | 9.1 | 5.2 | 11.9 | 0.0 | 141 |
| Guava | 1- 1 TO 12-31 | 365 | 50.4 | 62.5 | 57.8 | 7.0 | 9.1 | 18.0 | 30.2 | 5.5 | 489 |
| Heliconia | 1- 1 TO 12-31 | 365 | 50.4 | 62.5 | 62.6 | 7.1 | 9.1 | 24.2 | 35.9 | 9.8 | 657 |
| Kikuyu Grass | 1- 1 TO 12-31 | 365 | 50.4 | 62.5 | 62.6 | 7.3 | 9.1 | 26.0 | 39.4 | 11.3 | 706 |
| Lychee | 1- 1 TO 12-31 | 365 | 50.4 | 62.5 | 58.0 | 6.8 | 9.1 | 18.1 | 29.6 | 5.7 | 491 |
| Macadamia nut | 1- 1 TO 12-31 | 365 | 50.4 | 62.5 | 58.5 | 7.1 | 9.1 | 19.1 | 30.2 | 6.8 | 519 |
| Ti | 1- 1 TO 12-31 | 365 | 50.4 | 62.5 | 62.6 | 7.1 | 9.1 | 24.2 | 36.0 | 9.8 | 657 |

Appendix 9.10: East Kauai (Lihue Variety Station) Seasonal Irrigation Requirements for Selected Crops

| **Crop Type** | **Irrigation Season** | **Length** (day) | **Net Rainfall** (inch) | **Potential ET** (inch) | **Crop ET** (inch) | **Drainage** (inch) | **Runoff** (inch) | **Mean Irrigation Requirement** (inch) | **Maximum Irrigation Requirement** (inch) | **Minimum Irrigation Requirement** (inch) | **Mean Irrigation Requirement** (1000 gallons/acre) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alfalfa, initial | 11-15 TO 1-15 | 62 | 12.1 | 7.2 | 6.4 | 6.4 | 3.6 | 0.2 | 2.3 | 0.0 | 5 |
| Alfalfa, initial | 5-15 TO 7-15 | 62 | 8.8 | 10.8 | 9.3 | 1.3 | 0.6 | 0.9 | 4.0 | 0.0 | 24 |
| Alfalfa, ratoon | 11-15 TO 1-15 | 62 | 12.1 | 7.2 | 6.4 | 6.0 | 3.6 | 0.2 | 2.3 | 0.0 | 5 |
| Alfalfa, ratoon | 5-15 TO 7-15 | 62 | 8.8 | 10.8 | 9.3 | 1.0 | 0.6 | 0.8 | 2.4 | 0.0 | 22 |
| Banana, initial | 10- 1 TO 9-30 | 365 | 62.2 | 54.8 | 51.6 | 18.1 | 11.3 | 4.8 | 16.9 | 0.0 | 130 |
| Banana, initial | 5- 1 TO 4-30 | 365 | 62.2 | 54.8 | 48.9 | 16.5 | 11.3 | 2.0 | 7.6 | 0.0 | 54 |
| Banana, ratoon | 10- 1 TO 9-30 | 365 | 62.2 | 54.8 | 50.8 | 17.6 | 11.3 | 4.2 | 15.5 | 0.0 | 114 |
| Banana, ratoon | 5- 1 TO 4-30 | 365 | 62.2 | 54.8 | 48.3 | 16.1 | 11.3 | 1.7 | 6.2 | 0.0 | 46 |
| Cabbage | 11- 1 TO 1-31 | 92 | 18.2 | 10.9 | 9.9 | 9.5 | 5.9 | 0.8 | 3.5 | 0.0 | 22 |
| Cabbage | 5- 1 TO 7-31 | 92 | 14.0 | 16.0 | 14.2 | 2.5 | 1.2 | 2.2 | 6.0 | 0.4 | 60 |
| Cantaloupe | 10-15 TO 2-15 | 124 | 23.9 | 15.2 | 12.4 | 12.6 | 7.0 | 0.9 | 3.7 | 0.0 | 24 |
| Cantaloupe | 4-15 TO 8-15 | 123 | 19.1 | 21.3 | 17.1 | 4.2 | 1.7 | 2.0 | 5.2 | 0.0 | 54 |
| Dry Onion | 10-15 TO 2-15 | 124 | 23.9 | 15.2 | 14.5 | 11.3 | 7.0 | 1.6 | 5.8 | 0.0 | 43 |
| Dry Onion | 4-15 TO 8-15 | 123 | 19.1 | 21.3 | 20.4 | 3.3 | 1.7 | 4.0 | 9.0 | 0.5 | 109 |
| Eggplant | 10-15 TO 2-15 | 124 | 23.9 | 15.2 | 13.8 | 11.8 | 7.0 | 1.4 | 5.6 | 0.0 | 38 |
| Eggplant | 4-15 TO 8-15 | 123 | 19.1 | 21.3 | 19.2 | 3.7 | 1.7 | 3.3 | 7.9 | 0.4 | 90 |
| Ginger (AWD Potatoes) | 10- 1 TO 9-30 | 365 | 62.2 | 54.8 | 53.0 | 18.6 | 11.3 | 10.1 | 20.3 | 5.3 | 274 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ginger (AWD Potatoes) | 5- 1 TO 4-30 | 365 | 62.2 | 54.8 | 51.6 | 17.9 | 11.3 | 8.2 | 16.1 | 2.9 | 223 |
| Lettuce | 11-15 TO 1-15 | 62 | 12.1 | 7.2 | 6.2 | 6.8 | 3.6 | 0.9 | 3.5 | 0.0 | 24 |
| Lettuce | 5-15 TO 7-15 | 62 | 8.8 | 10.8 | 9.1 | 1.5 | 0.6 | 1.8 | 4.2 | 0.0 | 49 |
| Other Melon | 10-15 TO 2-15 | 124 | 23.9 | 15.2 | 13.8 | 11.8 | 7.0 | 1.5 | 5.8 | 0.0 | 41 |
| Other Melon | 4-15 TO 8-15 | 123 | 19.1 | 21.3 | 19.2 | 3.7 | 1.2 | 3.3 | 7.5 | 0.4 | 90 |
| Pineapple, year 1 | 10- 1 TO 9-30 | 365 | 62.2 | 54.8 | 33.0 | 29.0 | 11.3 | 0.0 | 1.2 | 0.0 | 0 |
| Pineapple, year 1 | 5- 1 TO 4-30 | 365 | 62.2 | 54.8 | 34.4 | 27.9 | 11.3 | 0.5 | 4.0 | 0.0 | 14 |
| Pineapple, year 2 | 10- 1 TO 9-30 | 365 | 62.2 | 54.8 | 35.0 | 26.7 | 11.3 | 0.1 | 1.2 | 0.0 | 3 |
| Pineapple, year 2 | 5- 1 TO 4-30 | 365 | 62.2 | 54.8 | 35.7 | 26.1 | 11.3 | 0.2 | 4.9 | 0.0 | 5 |
| Pumpkin | 10-15 TO 2-15 | 124 | 23.9 | 15.2 | 13.4 | 12.0 | 7.0 | 1.3 | 4.9 | 0.0 | 35 |
| Pumpkin | 4-15 TO 8-15 | 123 | 19.1 | 21.3 | 18.7 | 3.8 | 1.7 | 2.9 | 7.5 | 0.4 | 79 |
| Seed, Corn | 10-15 TO 2-15 | 124 | 23.9 | 15.2 | 14.6 | 10.6 | 7.0 | 1.0 | 5.0 | 0.0 | 27 |
| Seed, Corn | 4-15 TO 8-15 | 123 | 19.1 | 21.3 | 20.6 | 2.9 | 1.7 | 3.5 | 8.2 | 0.0 | 95 |
| Sugarcane, New- year 1 | 10- 1 TO 9-30 | 365 | 62.2 | 54.8 | 59.1 | 16.3 | 11.3 | 10.1 | 24.5 | 1.9 | 274 |
| Sugarcane, New- year 1 | 5- 1 TO 4-30 | 365 | 62.2 | 54.8 | 55.3 | 12.7 | 11.3 | 3.6 | 11.9 | 0.0 | 98 |
| Sugarcane, New- year 2 | 10- 1 TO 9-30 | 365 | 62.2 | 54.8 | 54.8 | 13.8 | 11.3 | 5.5 | 15.9 | 0.0 | 149 |
| Sugarcane, New- year 2 | 5- 1 TO 4-30 | 365 | 62.2 | 54.8 | 53.8 | 11.9 | 11.3 | 3.8 | 13.9 | 0.0 | 103 |
| Sugarcane, ratoon | 10- 1 TO 9-30 | 365 | 62.2 | 54.8 | 59.7 | 12.8 | 11.3 | 9.0 | 21.8 | 0.0 | 244 |
| Sugarcane, ratoon | 5- 1 TO 4-30 | 365 | 62.2 | 54.8 | 58.0 | 9.6 | 11.3 | 5.4 | 17.8 | 0.0 | 147 |
| Sweet potatoes | 10- 1 TO 2-28 | 151 | 28.7 | 19.0 | 18.6 | 12.2 | 7.9 | 1.8 | 7.6 | 0.0 | 49 |
| Sweet potatoes | 4- 1 TO 8-31 | 153 | 24.3 | 26.4 | 26.0 | 4.1 | 2.1 | 5.6 | 13.5 | 0.0 | 152 |
| Taro | 10- 1 TO 9-30 | 365 | 62.2 | 54.8 | 60.8 | 38.8 | 11.3 | 75.6 | 84.1 | 67.9 | 2053 |
| Taro | 5- 1 TO 4-30 | 365 | 62.2 | 54.8 | 60.2 | 38.9 | 11.3 | 74.3 | 82.4 | 60.5 | 2018 |
| Tomato | 10-15 TO 2-15 | 124 | 23.9 | 15.2 | 14.6 | 11.2 | 7.0 | 1.6 | 6.7 | 0.0 | 43 |
| Tomato | 4-15 TO 8-15 | 123 | 19.1 | 21.3 | 20.5 | 3.3 | 1.7 | 4.2 | 9.6 | 0.5 | 114 |
| Watermelon | 10-15 TO 2-15 | 124 | 23.9 | 15.2 | 13.5 | 11.9 | 7.1 | 1.3 | 5.1 | 0.2 | 35 |
| Watermelon | 4-15 TO 8-15 | 123 | 19.1 | 21.3 | 18.8 | 3.7 | 1.7 | 3.1 | 7.1 | 0.3 | 84 |
| Coffee | 1- 1 TO 12-31 | 365 | 62.3 | 54.8 | 51.6 | 15.2 | 11.3 | 5.7 | 19.1 | 0.0 | 155 |
| Dendrobium, pot, micro-sprink | 1- 1 TO 12-31 | 365 | 62.3 | 54.8 | 54.9 | 25.7 | 11.3 | 22.7 | 32.8 | 14.3 | 616 |
| Dendrobium, pot, nursery spray | 1- 1 TO 12-31 | 365 | 62.3 | 54.8 | 54.9 | 33.2 | 11.3 | 120 | 143 | 105 | 3259 |
| Draceana, pot micro- | 1- 1 TO 12-31 | 365 | 62.3 | 54.8 | 54.9 | 23.9 | 11.3 | 20.5 | 33.6 | 13.3 | 557 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| sprink | | | | | | | | | | | |
| Draceana, pot, nursery spray | 1- 1 TO 12-31 | 365 | 62.3 | 54.8 | 54.9 | 30.5 | 11.3 | 115 | 140 | 96 | 3123 |
| Eucaluptus closed canopy | 1- 1 TO 12-31 | 365 | 62.3 | 54.8 | 54.9 | 12.9 | 11.3 | 6.9 | 22.5 | 0.0 | 187 |
| Eucalyptus young | 1- 1 TO 12-31 | 365 | 62.3 | 54.8 | 39.9 | 22.6 | 11.3 | 0.2 | 4.3 | 0.0 | 5 |
| Guava | 1- 1 TO 12-31 | 365 | 62.3 | 54.8 | 51.1 | 14.4 | 11.3 | 4.0 | 16.2 | 0.0 | 109 |
| Heliconia | 1- 1 TO 12-31 | 365 | 62.3 | 54.8 | 54.9 | 13.3 | 11.3 | 7.3 | 22.4 | 1.1 | 198 |
| Kikuyu Grass | 1- 1 TO 12-31 | 365 | 62.3 | 54.8 | 54.9 | 13.3 | 11.3 | 7.8 | 23.8 | 0.0 | 212 |
| Lychee | 1- 1 TO 12-31 | 365 | 62.3 | 54.8 | 51.4 | 14.4 | 11.3 | 4.4 | 16.6 | 0.0 | 119 |
| Macadamia nut | 1- 1 TO 12-31 | 365 | 62.3 | 54.8 | 51.6 | 14.4 | 11.3 | 4.7 | 16.8 | 0.0 | 128 |
| Ti | 1- 1 TO 12-31 | 365 | 62.3 | 54.8 | 54.9 | 13.3 | 11.3 | 7.4 | 22.4 | 1.1 | 201 |

Appendix 9.11: Molokai (Kualapuu and Kaunakakai stations) Seasonal Irrigation Requirements for Selected Crops

| **Crop Type** | **Irrigation Season** | **Length** (day) | **Net Rainfall** (inch) | **Potential ET** (inch) | **Crop ET** (inch) | **Drainage** (inch) | **Runoff** (inch) | **Mean Irrigation Requirement** (inch) | **Maximum Irrigation Requirement** (inch) | **Minimum Irrigation Requirement** (inch) | **Mean Irrigation Requirement** (1000 gallons/acre) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alfalfa, initial | 11-15 TO 1-15 | 62 | 7.7 | 13.2 | 10.8 | 1.9 | 2.0 | 4.6 | 9.4 | 0.0 | 125 |
| Alfalfa, initial | 5-15 TO 7-15 | 62 | 1.9 | 18.6 | 15.0 | 0.1 | 0.1 | 13.8 | 16.1 | 11.3 | 375 |
| Alfalfa, ratoon | 11-15 TO 1-15 | 62 | 7.7 | 13.2 | 10.8 | 1.4 | 2.0 | 4.1 | 8.1 | 0.0 | 111 |
| Alfalfa, ratoon | 5-15 TO 7-15 | 62 | 1.9 | 18.6 | 14.9 | 0.1 | 0.1 | 13.6 | 14.8 | 12.1 | 369 |
| Banana, initial | 10- 1 TO 9-30 | 365 | 28.1 | 94.2 | 84.1 | 2.8 | 5.8 | 62.8 | 75.8 | 47.3 | 1705 |
| Banana, initial | 5- 1 TO 4-30 | 365 | 28.0 | 94.2 | 77.6 | 0.1 | 5.8 | 53.3 | 67.7 | 34.4 | 1447 |
| Banana, ratoon | 10- 1 TO 9-30 | 365 | 28.1 | 94.2 | 82.2 | 2.0 | 5.8 | 60.1 | 73.9 | 44.4 | 1632 |
| Banana, ratoon | 5- 1 TO 4-30 | 365 | 28.0 | 94.2 | 74.3 | 0.1 | 5.8 | 49.7 | 63.2 | 32.1 | 1350 |
| Cabbage | 11- 1 TO 1-31 | 92 | 11.3 | 19.8 | 16.8 | 2.2 | 3.0 | 7.8 | 14.3 | 3.0 | 212 |
| Cabbage | 5- 1 TO 7-31 | 92 | 3.0 | 27.3 | 23.3 | 0.1 | 0.1 | 20.5 | 22.9 | 16.5 | 557 |
| Cantaloupe | 10-15 TO 2-15 | 124 | 14.5 | 27.2 | 20.5 | 2.8 | 3.7 | 9.3 | 15.6 | 4.5 | 253 |
| Cantaloupe | 4-15 TO 8-15 | 123 | 4.6 | 36.1 | 26.8 | 0.1 | 0.3 | 22.6 | 25.8 | 17.3 | 614 |
| Dry Onion | 10-15 TO 2-15 | 124 | 14.5 | 27.2 | 25.3 | 1.9 | 3.7 | 13.2 | 20.3 | 6.7 | 358 |
| Dry Onion | 4-15 TO 8-15 | 123 | 4.6 | 36.1 | 33.9 | 0.1 | 0.3 | 29.6 | 33.4 | 24.0 | 804 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Eggplant | 10-15 TO 2-15 | 124 | 14.5 | 27.2 | 23.5 | 2.2 | 3.7 | 11.8 | 18.5 | 6.0 | 320 |
| Eggplant | 4-15 TO 8-15 | 123 | 4.6 | 36.1 | 31.6 | 0.1 | 0.3 | 27.3 | 31.2 | 21.2 | 741 |
| Ginger (AWD Potatoes) | 10- 1 TO 9-30 | 365 | 28.1 | 94.2 | 88.8 | 3.0 | 5.8 | 66.8 | 78.5 | 54.1 | 1814 |
| Ginger (AWD Potatoes) | 5- 1 TO 4-30 | 365 | 28.0 | 94.2 | 87.3 | 1.2 | 5.8 | 67.7 | 79.2 | 52.8 | 1838 |
| Lettuce | 11-15 TO 1-15 | 62 | 7.7 | 13.2 | 10.7 | 2.4 | 2.0 | 6.3 | 10.4 | 1.3 | 171 |
| Lettuce | 5-15 TO 7-15 | 62 | 1.9 | 18.6 | 15.0 | 0.1 | 0.1 | 15.5 | 17.6 | 12.8 | 421 |
| Other Melon | 10-15 TO 2-15 | 124 | 14.5 | 27.2 | 23.5 | 2.2 | 3.7 | 11.9 | 18.9 | 6.4 | 323 |
| Other Melon | 4-15 TO 8-15 | 123 | 4.6 | 36.1 | 31.5 | 0.1 | 0.1 | 27.3 | 31.4 | 21.4 | 741 |
| Pineapple, year 1 | 10- 1 TO 9-30 | 365 | 28.1 | 94.2 | 41.3 | 4.4 | 5.8 | 16.3 | 24.7 | 7.9 | 443 |
| Pineapple, year 1 | 5- 1 TO 4-30 | 365 | 28.0 | 94.2 | 46.3 | 4.9 | 5.8 | 25.5 | 31.3 | 18.3 | 692 |
| Pineapple, year 2 | 10- 1 TO 9-30 | 365 | 28.1 | 94.2 | 43.9 | 3.4 | 5.8 | 18.4 | 29.0 | 9.5 | 500 |
| Pineapple, year 2 | 5- 1 TO 4-30 | 365 | 28.0 | 94.2 | 46.4 | 3.8 | 5.8 | 24.5 | 31.7 | 17.2 | 665 |
| Pumpkin | 10-15 TO 2-15 | 124 | 14.5 | 27.2 | 22.9 | 2.4 | 3.7 | 11.3 | 18.3 | 5.9 | 307 |
| Pumpkin | 4-15 TO 8-15 | 123 | 4.6 | 36.1 | 30.6 | 0.1 | 0.3 | 26.0 | 29.8 | 20.2 | 706 |
| Seed, Corn | 10-15 TO 2-15 | 124 | 14.5 | 27.2 | 24.6 | 1.4 | 3.7 | 11.7 | 19.6 | 5.3 | 318 |
| Seed, Corn | 4-15 TO 8-15 | 123 | 4.6 | 36.1 | 33.3 | 0.1 | 0.3 | 29.1 | 33.1 | 24.0 | 790 |
| Sugarcane, New- year 1 | 10- 1 TO 9-30 | 365 | 28.1 | 94.2 | 96.9 | 2.3 | 5.8 | 75.5 | 89.2 | 59.6 | 2050 |
| Sugarcane, New- year 1 | 5- 1 TO 4-30 | 365 | 28.0 | 94.2 | 89.3 | 0.1 | 5.8 | 65.0 | 79.8 | 44.9 | 1765 |
| Sugarcane, New- year 2 | 10- 1 TO 9-30 | 365 | 28.1 | 94.2 | 89.3 | 0.9 | 5.8 | 65.7 | 81.5 | 49.6 | 1784 |
| Sugarcane, New- year 2 | 5- 1 TO 4-30 | 365 | 28.0 | 94.2 | 88.0 | 0.2 | 5.8 | 65.3 | 78.6 | 48.8 | 1773 |
| Sugarcane, ratoon | 10- 1 TO 9-30 | 365 | 28.1 | 94.2 | 98.7 | 0.7 | 5.8 | 76.6 | 92.5 | 60.9 | 2080 |
| Sugarcane, ratoon | 5- 1 TO 4-30 | 365 | 28.0 | 94.2 | 96.6 | 0.1 | 5.8 | 74.7 | 89.2 | 57.2 | 2028 |
| Sweet potatoes | 10- 1 TO 2-28 | 151 | 16.9 | 33.8 | 31.6 | 1.7 | 3.9 | 17.6 | 26.5 | 9.8 | 478 |
| Sweet potatoes | 4- 1 TO 8-31 | 153 | 6.3 | 44.5 | 42.5 | 0.3 | 0.7 | 37.9 | 42.5 | 31.6 | 1029 |
| Taro | 10- 1 TO 9-30 | 365 | 28.1 | 94.2 | 104.3 | 14.9 | 5.8 | 183.0 | 194.0 | 175.0 | 4969 |
| Taro | 5- 1 TO 4-30 | 365 | 28.0 | 94.2 | 103.5 | 14.6 | 5.8 | 181.0 | 191.0 | 169.0 | 4915 |
| Tomato | 10-15 TO 2-15 | 124 | 14.5 | 27.2 | 25.0 | 1.9 | 3.7 | 13.1 | 20.5 | 6.8 | 356 |
| Tomato | 4-15 TO 8-15 | 123 | 4.6 | 36.1 | 33.8 | 0.1 | 0.3 | 29.3 | 33.1 | 23.2 | 796 |
| Watermelon | 10-15 TO 2-15 | 124 | 14.5 | 27.2 | 23.2 | 2.3 | 3.7 | 11.7 | 18.4 | 6.4 | 318 |
| Watermelon | 4-15 TO 8-15 | 123 | 4.6 | 36.1 | 30.9 | 0.1 | 0.3 | 26.5 | 29.7 | 20.7 | 720 |
| Coffee | 1- 1 TO 12-31 | 365 | 27.9 | 94.2 | 87.0 | 1.2 | 5.8 | 75.2 | 93.4 | 55.5 | 2042 |
| Dendrobium, pot, micro- | 1- 1 TO 12-31 | 365 | 27.9 | 94.2 | 94.1 | 6.8 | 5.8 | 90.7 | 104 | 75.5 | 2463 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| sprink | | | | | | | | | | | |
| Dendrobium, pot, nursery spray | 1- 1 TO 12-31 | 365 | 27.9 | 94.2 | 94.1 | 11.6 | 5.8 | 291 | 311 | 264 | 7902 |
| Draceana, pot micro-sprink | 1- 1 TO 12-31 | 365 | 27.9 | 94.2 | 94.1 | 6.2 | 5.8 | 90.1 | 102.9 | 75.7 | 2447 |
| Draceana, pot, nursery spray | 1- 1 TO 12-31 | 365 | 27.9 | 94.2 | 94.1 | 10.7 | 5.8 | 290 | 312 | 262 | 7875 |
| Eucaluptus closed canopy | 1- 1 TO 12-31 | 365 | 27.9 | 94.2 | 94.1 | 1.5 | 5.8 | 84.4 | 103.2 | 62.3 | 2292 |
| Eucalyptus young | 1- 1 TO 12-31 | 365 | 27.9 | 94.2 | 59.6 | 1.3 | 5.8 | 41.0 | 56.6 | 26.4 | 1113 |
| Guava | 1- 1 TO 12-31 | 365 | 27.9 | 94.2 | 85.7 | 0.6 | 5.8 | 72.7 | 92.0 | 53.6 | 1974 |
| Heliconia | 1- 1 TO 12-31 | 365 | 27.9 | 94.2 | 94.1 | 0.8 | 5.8 | 83.5 | 103.2 | 62.2 | 2267 |
| Kikuyu Grass | 1- 1 TO 12-31 | 365 | 27.9 | 94.2 | 94.1 | 1.0 | 5.8 | 89.4 | 110.6 | 67.7 | 2428 |
| Lychee | 1- 1 TO 12-31 | 365 | 27.9 | 94.2 | 86.0 | 0.5 | 5.8 | 73.0 | 92.6 | 54.0 | 1982 |
| Macadamia nut | 1- 1 TO 12-31 | 365 | 27.9 | 94.2 | 87.0 | 0.7 | 5.8 | 74.6 | 93.0 | 55.6 | 2026 |
| Ti | 1- 1 TO 12-31 | 365 | 27.9 | 94.2 | 94.1 | 0.8 | 5.8 | 83.5 | 102.6 | 62.8 | 2267 |

Appendix 9.12: West Maui (Pohakea Bridge and Field 906 stations) Seasonal Irrigation Requirements for Selected Crops

| **Crop Type** | **Irrigation Season** | **Length** (day) | **Net Rainfall** (inch) | **Potential ET** (inch) | **Crop ET** (inch) | **Drainage** (inch) | **Runoff** (inch) | **Mean Irrigation Requirement** (inch) | **Maximum Irrigation Requirement** (inch) | **Minimum Irrigation Requirement** (inch) | **Mean Irrigation Requirement** (1000 gallons/acre) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alfalfa, initial | 11-15 TO 1-15 | 62 | 5.3 | 9.7 | 7.8 | 1.4 | 1.4 | 3.5 | 7.0 | 0.0 | 95 |
| Alfalfa, initial | 5-15 TO 7-15 | 62 | 0.5 | 16.2 | 13.0 | 0.1 | 0.0 | 12.7 | 14.3 | 9.6 | 345 |
| Alfalfa, ratoon | 11-15 TO 1-15 | 62 | 4.1 | 13.3 | 10.5 | 0.4 | 1.4 | 6.9 | 11.0 | 2.2 | 187 |
| Alfalfa, ratoon | 5-15 TO 7-15 | 62 | 0.5 | 16.2 | 12.9 | 0.0 | 0.0 | 13.0 | 13.6 | 8.9 | 353 |
| Banana, initial | 10- 1 TO 9-30 | 365 | 16.0 | 77.7 | 69.1 | 2.0 | 3.3 | 57.3 | 68.2 | 47.5 | 1556 |
| Banana, initial | 5- 1 TO 4-30 | 365 | 16.0 | 77.7 | 61.2 | 0.1 | 3.3 | 46.9 | 59.1 | 29.8 | 1274 |
| Banana, ratoon | 10- 1 TO 9-30 | 365 | 16.0 | 77.7 | 67.4 | 1.3 | 3.3 | 55.1 | 66.9 | 41.7 | 1496 |
| Banana, ratoon | 5- 1 TO 4-30 | 365 | 16.0 | 77.7 | 58.6 | 0.1 | 3.3 | 44.3 | 56.5 | 26.1 | 1203 |
| Cabbage | 11- 1 TO 1-31 | 92 | 7.8 | 14.8 | 12.1 | 1.8 | 2.0 | 5.9 | 9.2 | 1.4 | 160 |
| Cabbage | 5- 1 TO 7-31 | 92 | 1.0 | 23.8 | 20.2 | 0.0 | 0.1 | 19.8 | 21.2 | 15.5 | 538 |
| Cantaloupe | 10-15 TO 2-15 | 124 | 9.9 | 20.7 | 15.2 | 2.1 | 2.3 | 7.7 | 11.3 | 3.2 | 209 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cantaloupe | 4-15 TO 8-15 | 123 | 1.7 | 31.3 | 23 | 0.1 | 0.1 | 22.5 | 24.1 | 18.5 | 611 |
| Dry Onion | 10-15 TO 2-15 | 124 | 9.9 | 20.7 | 19.0 | 1.6 | 2.3 | 11.1 | 16.1 | 5.5 | 301 |
| Dry Onion | 4-15 TO 8-15 | 123 | 1.7 | 31.3 | 29.2 | 0.1 | 0.1 | 29.2 | 31.2 | 24.4 | 793 |
| Eggplant | 10-15 TO 2-15 | 124 | 9.9 | 20.7 | 17.3 | 1.8 | 2.3 | 9.5 | 13.8 | 4.1 | 258 |
| Eggplant | 4-15 TO 8-15 | 123 | 1.7 | 31.3 | 27.3 | 0.1 | 0.1 | 27.5 | 29.5 | 23.0 | 747 |
| Ginger (AWD Potatoes) | 10- 1 TO 9-30 | 365 | 16.0 | 77.7 | 72.6 | 2.3 | 3.3 | 65.4 | 75.7 | 55.1 | 1776 |
| Ginger (AWD Potatoes) | 5- 1 TO 4-30 | 365 | 16.0 | 77.7 | 71.6 | 1.6 | 3.3 | 64.8 | 75.6 | 52.8 | 1760 |
| Lettuce | 11-15 TO 1-15 | 62 | 5.3 | 9.7 | 7.6 | 1.9 | 1.4 | 5.0 | 7.8 | 0.9 | 136 |
| Lettuce | 5-15 TO 7-15 | 62 | 0.5 | 16.2 | 12.9 | 0.1 | 0.0 | 14.7 | 15.5 | 11.9 | 399 |
| Other Melon | 10-15 TO 2-15 | 124 | 9.9 | 20.7 | 17.4 | 1.8 | 2.3 | 9.6 | 14.3 | 4.3 | 261 |
| Other Melon | 4-15 TO 8-15 | 123 | 1.7 | 31.3 | 27.3 | 0.1 | 0.1 | 27.4 | 29.3 | 22.8 | 744 |
| Pineapple, year 1 | 10- 1 TO 9-30 | 365 | 16.0 | 77.7 | 30.3 | 3.2 | 3.3 | 15.3 | 22.6 | 9.0 | 415 |
| Pineapple, year 1 | 5- 1 TO 4-30 | 365 | 16.0 | 77.7 | 35.2 | 2.7 | 3.3 | 23.1 | 29.0 | 17.1 | 627 |
| Pineapple, year 2 | 10- 1 TO 9-30 | 365 | 16.0 | 77.7 | 31.9 | 2.3 | 3.3 | 16.5 | 24.9 | 10.2 | 448 |
| Pineapple, year 2 | 5- 1 TO 4-30 | 365 | 16.0 | 77.7 | 34.7 | 2.0 | 3.3 | 22.1 | 28.5 | 16.2 | 600 |
| Pumpkin | 10-15 TO 2-15 | 124 | 9.9 | 20.7 | 16.9 | 1.9 | 2.3 | 9.1 | 13.6 | 4.1 | 247 |
| Pumpkin | 4-15 TO 8-15 | 123 | 1.7 | 31.3 | 26.4 | 0.1 | 0.1 | 26.4 | 28.2 | 22.0 | 717 |
| Seed, Corn | 10-15 TO 2-15 | 124 | 9.9 | 20.7 | 18.3 | 1.2 | 2.3 | 9.2 | 13.8 | 2.1 | 250 |
| Seed, Corn | 4-15 TO 8-15 | 123 | 1.7 | 31.3 | 28.7 | 0.1 | 0.1 | 27.8 | 29.8 | 22.9 | 755 |
| Sugarcane, New- year 1 | 10- 1 TO 9-30 | 365 | 16.0 | 77.7 | 79.9 | 1.6 | 3.3 | 68.4 | 78.9 | 56.6 | 1857 |
| Sugarcane, New- year 1 | 5- 1 TO 4-30 | 365 | 16.0 | 77.7 | 71.2 | 0.1 | 3.3 | 57.4 | 69.8 | 39.4 | 1559 |
| Sugarcane, New- year 2 | 10- 1 TO 9-30 | 365 | 16.0 | 77.7 | 72.2 | 0.7 | 3.3 | 59.1 | 71.8 | 44.1 | 1605 |
| Sugarcane, New- year 2 | 5- 1 TO 4-30 | 365 | 16.0 | 77.7 | 72.2 | 0.2 | 3.3 | 60.1 | 72.1 | 46.6 | 1632 |
| Sugarcane, ratoon | 10- 1 TO 9-30 | 365 | 16.0 | 77.7 | 80.3 | 0.6 | 3.3 | 68.4 | 80.4 | 51.8 | 1857 |
| Sugarcane, ratoon | 5- 1 TO 4-30 | 365 | 16.0 | 77.7 | 79.1 | 0.1 | 3.3 | 67.6 | 79.1 | 50.0 | 1836 |
| Sweet potatoes | 10- 1 TO 2-28 | 151 | 11.1 | 26.1 | 23.6 | 1.4 | 2.6 | 14.7 | 20.6 | 8.0 | 399 |
| Sweet potatoes | 4- 1 TO 8-31 | 153 | 2.6 | 38.3 | 36.6 | 0.4 | 0.3 | 37.5 | 40.0 | 33.4 | 1018 |
| Taro | 10- 1 TO 9-30 | 365 | 16.0 | 77.7 | 86.0 | 10.1 | 3.3 | 161.0 | 168.0 | 154.0 | 4372 |
| Taro | 5- 1 TO 4-30 | 365 | 16.0 | 77.7 | 85.1 | 9.9 | 3.3 | 159.0 | 165.0 | 149.0 | 4318 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Tomato | 10-15 TO 2-15 | 124 | 9.9 | 20.7 | 18.5 | 1.7 | 2.3 | 10.6 | 15.7 | 4.3 | 288 |
| Tomato | 4-15 TO 8-15 | 123 | 1.7 | 31.3 | 29.2 | 0.1 | 0.1 | 29.6 | 31.5 | 25.3 | 804 |
| Watermelon | 10-15 TO 2-15 | 124 | 9.9 | 20.7 | 17.3 | 1.9 | 2.3 | 9.7 | 13.9 | 4.7 | 263 |
| Watermelon | 4-15 TO 8-15 | 123 | 1.7 | 31.3 | 26.6 | 0.1 | 0.1 | 26.5 | 28.3 | 22.2 | 720 |
| Coffee | 1- 1 TO 12-31 | 365 | 16.1 | 77.7 | 71.8 | 0.7 | 3.3 | 70.5 | 83.6 | 56.3 | 1914 |
| Dendrobium, pot, micro-sprink | 1- 1 TO 12-31 | 365 | 16.1 | 77.7 | 77.6 | 5.8 | 3.3 | 84 | 93.2 | 74.4 | 2281 |
| Dendrobium, pot, nursery spray | 1- 1 TO 12-31 | 365 | 16.1 | 77.7 | 77.6 | 8.3 | 3.3 | 252 | 266 | 235 | 6843 |
| Draceana, pot micro-sprink | 1- 1 TO 12-31 | 365 | 16.1 | 77.7 | 77.6 | 5 | 3.3 | 83.1 | 91.8 | 73.7 | 2257 |
| Draceana, pot, nursery spray | 1- 1 TO 12-31 | 365 | 16.1 | 77.7 | 77.6 | 7.6 | 3.3 | 251 | 265 | 233 | 6816 |
| Eucaluptus closed canopy | 1- 1 TO 12-31 | 365 | 16.1 | 77.7 | 77.6 | 1.2 | 3.3 | 78.2 | 91.1 | 61.0 | 2123 |
| Eucalyptus young | 1- 1 TO 12-31 | 365 | 16.1 | 77.7 | 48.2 | 0.7 | 3.3 | 40.8 | 54.4 | 26.2 | 1108 |
| Guava | 1- 1 TO 12-31 | 365 | 16.1 | 77.7 | 70.5 | 0.4 | 3.3 | 68.3 | 81.6 | 52.7 | 1855 |
| Heliconia | 1- 1 TO 12-31 | 365 | 16.1 | 77.7 | 77.6 | 0.6 | 3.3 | 77.5 | 90.6 | 62.0 | 2104 |
| Kikuyu Grass | 1- 1 TO 12-31 | 365 | 16.1 | 77.7 | 77.6 | 0.9 | 3.3 | 83.2 | 99.0 | 66.9 | 2259 |
| Lychee | 1- 1 TO 12-31 | 365 | 16.1 | 77.7 | 70.5 | 0.3 | 3.3 | 68.3 | 84.6 | 52.1 | 1855 |
| Macadamia nut | 1- 1 TO 12-31 | 365 | 16.1 | 77.7 | 71.8 | 0.4 | 3.3 | 70.0 | 83.8 | 53.9 | 1901 |
| Ti | 1- 1 TO 12-31 | 365 | 16.1 | 77.7 | 77.6 | 0.6 | 3.3 | 77.5 | 90.6 | 61.9 | 2104 |

Appendix 9.13: Kula (Kula Station) seasonal Seasonal Irrigation Requirements for Selected Crops

| **Crop Type** | **Irrigation Season** | **Length** (day) | **Net Rainfall** (inch) | **Potential ET** (inch) | **Crop ET** (inch) | **Drainage** (inch) | **Runoff** (inch) | **Mean Irrigation Requirement** (inch) | **Maximum Irrigation Requirement** (inch) | **Minimum Irrigation Requirement** (inch) | **Mean Irrigation Requirement** (1000 gallons/acre) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alfalfa, initial | 11-15 TO 1-15 | 62 | 5.4 | 6.0 | 4.9 | 2.1 | 1.5 | 1.1 | 4.4 | 0.0 | 30 |
| Alfalfa, initial | 5-15 TO 7-15 | 62 | 1.8 | 10.2 | 8.2 | 0.1 | 0.1 | 5.4 | 9.2 | 2.3 | 147 |
| Alfalfa, ratoon | 11-15 TO 1-15 | 62 | 5.4 | 6.0 | 4.9 | 1.8 | 1.5 | 1.0 | 4.6 | 0.0 | 27 |
| Alfalfa, ratoon | 5-15 TO 7-15 | 62 | 1.8 | 10.2 | 8.2 | 0.0 | 0.1 | 5.6 | 9.1 | 2.3 | 152 |
| Banana, initial | 10- 1 TO 9-30 | 365 | 20.4 | 49.5 | 44.3 | 3.1 | 3.4 | 24.3 | 32.8 | 14.0 | 660 |
| Banana, initial | 5- 1 TO 4-30 | 365 | 20.1 | 49.5 | 39.4 | 6.3 | 3.4 | 18.0 | 27.7 | 7.5 | 489 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Banana, ratoon | 10- 1 TO 9-30 | 365 | 20.4 | 49.5 | 43.5 | 1.0 | 3.4 | 23.2 | 31.1 | 12.2 | 630 |
| Banana, ratoon | 5- 1 TO 4-30 | 365 | 20.1 | 49.5 | 38.5 | 0.3 | 3.4 | 17.0 | 26.0 | 7.5 | 462 |
| Cabbage | 11- 1 TO 1-31 | 92 | 7.6 | 9.2 | 7.6 | 3.0 | 1.8 | 2.4 | 5.4 | 0.4 | 65 |
| Cabbage | 5- 1 TO 7-31 | 92 | 3.0 | 15.0 | 12.5 | 0.4 | 0.2 | 8.9 | 12.2 | 4.9 | 242 |
| Cantaloupe | 10-15 TO 2-15 | 124 | 9.7 | 12.9 | 9.5 | 3.4 | 2.1 | 3.1 | 5.2 | 1.1 | 84 |
| Cantaloupe | 4-15 TO 8-15 | 123 | 4.3 | 19.9 | 14.6 | 0.4 | 0.3 | 10.2 | 12.3 | 5.7 | 277 |
| Dry Onion | 10-15 TO 2-15 | 124 | 9.7 | 12.9 | 11.8 | 2.7 | 2.1 | 4.5 | 7.6 | 1.9 | 122 |
| Dry Onion | 4-15 TO 8-15 | 123 | 4.3 | 19.9 | 18.5 | 0.4 | 0.3 | 14.3 | 17.0 | 8.8 | 388 |
| Eggplant | 10-15 TO 2-15 | 124 | 9.7 | 12.9 | 10.8 | 3.0 | 2.1 | 3.9 | 7.0 | 1.0 | 106 |
| Eggplant | 4-15 TO 8-15 | 123 | 4.3 | 19.9 | 17.1 | 0.4 | 0.3 | 12.9 | 15.4 | 8.0 | 350 |
| Ginger (AWD Potatoes) | 10- 1 TO 9-30 | 365 | 20.4 | 49.5 | 46.4 | 4.1 | 3.4 | 33.3 | 42.7 | 19.9 | 904 |
| Ginger (AWD Potatoes) | 5- 1 TO 4-30 | 365 | 20.1 | 49.5 | 45.2 | 3.3 | 3.4 | 31.3 | 40.3 | 21.8 | 850 |
| Lettuce | 11-15 TO 1-15 | 62 | 5.4 | 6.0 | 4.7 | 2.8 | 1.5 | 2.3 | 4.4 | 0.5 | 62 |
| Lettuce | 5-15 TO 7-15 | 62 | 1.8 | 10.2 | 8.0 | 0.2 | 0.1 | 6.9 | 9.8 | 3.3 | 187 |
| Other Melon | 10-15 TO 2-15 | 124 | 9.7 | 12.9 | 10.7 | 3.1 | 2.1 | 4.1 | 7.1 | 1.5 | 111 |
| Other Melon | 4-15 TO 8-15 | 123 | 4.3 | 19.9 | 17.0 | 0.4 | 0.2 | 12.8 | 15.5 | 7.6 | 348 |
| Pineapple, year 1 | 10- 1 TO 9-30 | 365 | 20.4 | 49.5 | 20.3 | 7.3 | 3.4 | 3.8 | 7.1 | 0.0 | 103 |
| Pineapple, year 1 | 5- 1 TO 4-30 | 365 | 20.1 | 49.5 | 21.7 | 12.1 | 3.4 | 6.7 | 11.2 | 1.9 | 182 |
| Pineapple, year 2 | 10- 1 TO 9-30 | 365 | 20.4 | 49.5 | 21.5 | 3.8 | 3.4 | 4.1 | 9.6 | 0.0 | 111 |
| Pineapple, year 2 | 5- 1 TO 4-30 | 365 | 20.1 | 49.5 | 22.6 | 4.3 | 3.4 | 6.8 | 10.9 | 2.4 | 185 |
| Pumpkin | 10-15 TO 2-15 | 124 | 2.8 | 3.3 | 2.8 | 1.0 | 2.1 | 0.6 | 1.6 | 0.0 | 16 |
| Pumpkin | 4-15 TO 8-15 | 123 | 4.3 | 19.9 | 16.5 | 0.4 | 0.3 | 12.2 | 14.5 | 7.4 | 331 |
| Seed, Corn | 10-15 TO 2-15 | 124 | 9.7 | 12.9 | 11.5 | 2.1 | 2.1 | 3.1 | 6.7 | 0.7 | 84 |
| Seed, Corn | 4-15 TO 8-15 | 123 | 4.3 | 19.9 | 18.2 | 0.3 | 0.3 | 12.6 | 15.7 | 6.8 | 342 |
| Sugarcane, New- year 1 | 10- 1 TO 9-30 | 365 | 20.4 | 49.5 | 51.5 | 2.4 | 3.4 | 32.2 | 40.8 | 18.2 | 874 |
| Sugarcane, New- year 1 | 5- 1 TO 4-30 | 365 | 20.1 | 49.5 | 46.1 | 1.7 | 3.4 | 24.8 | 36.2 | 12.3 | 673 |
| Sugarcane, New- year 2 | 10- 1 TO 9-30 | 365 | 20.4 | 49.5 | 47.1 | 0.5 | 3.4 | 26.3 | 36.5 | 9.9 | 714 |
| Sugarcane, New- year 2 | 5- 1 TO 4-30 | 365 | 20.1 | 49.5 | 46.3 | 0.4 | 3.4 | 26.4 | 36.3 | 15.9 | 717 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sugarcane, ratoon | 10- 1 TO 9-30 | 365 | 20.4 | 49.5 | 52.1 | 0.4 | 3.4 | 31.6 | 42.5 | 13.7 | 858 |
| Sugarcane, ratoon | 5- 1 TO 4-30 | 365 | 20.1 | 49.5 | 50.6 | 0.3 | 3.4 | 30.6 | 42.2 | 17.8 | 831 |
| Sweet potatoes | 10- 1 TO 2-28 | 151 | 11.3 | 16.4 | 14.9 | 2.6 | 2.4 | 6.1 | 9.6 | 3.1 | 166 |
| Sweet potatoes | 4- 1 TO 8-31 | 153 | 5.5 | 24.5 | 23.3 | 0.6 | 0.5 | 18.9 | 22.8 | 12.3 | 513 |
| Taro | 10- 1 TO 9-30 | 365 | 20.4 | 49.5 | 55.0 | 5.5 | 3.4 | 98.5 | 110.7 | 86.0 | 2675 |
| Taro | 5- 1 TO 4-30 | 365 | 20.1 | 49.5 | 54.3 | 5.4 | 3.4 | 97.1 | 104.4 | 88.0 | 2637 |
| Tomato | 10-15 TO 2-15 | 124 | 9.7 | 12.9 | 11.5 | 2.8 | 2.1 | 4.3 | 8.1 | 1.5 | 117 |
| Tomato | 4-15 TO 8-15 | 123 | 4.3 | 19.9 | 18.3 | 0.4 | 0.3 | 14.2 | 17.0 | 8.8 | 386 |
| Watermelon | 10-15 TO 2-15 | 124 | 9.7 | 12.9 | 10.7 | 3.1 | 2.1 | 4.0 | 7.0 | 1.5 | 109 |
| Watermelon | 4-15 TO 8-15 | 123 | 4.3 | 19.9 | 16.7 | 0.4 | 0.3 | 12.6 | 15.2 | 7.7 | 342 |
| Coffee | 1- 1 TO 12-31 | 365 | 20.4 | 49.5 | 45.9 | 1.6 | 3.4 | 33.7 | 45.5 | 16.6 | 915 |
| Dendrobium, pot, micro-sprink | 1- 1 TO 12-31 | 365 | 20.4 | 49.5 | 49.6 | 8.9 | 3.4 | 47.6 | 54.9 | 36.7 | 1293 |
| Dendrobium, pot, nursery spray | 1- 1 TO 12-31 | 365 | 20.4 | 49.5 | 49.6 | 12.3 | 3.4 | 153 | 169 | 129 | 4155 |
| Draceana, pot micro-sprink | 1- 1 TO 12-31 | 365 | 20.4 | 49.5 | 49.6 | 8.4 | 3.4 | 46.9 | 54.6 | 35.1 | 1274 |
| Draceana, pot, nursery spray | 1- 1 TO 12-31 | 365 | 20.4 | 49.5 | 49.6 | 11.2 | 3.4 | 151 | 169 | 125 | 4100 |
| Eucaluptus closed canopy | 1- 1 TO 12-31 | 365 | 20.4 | 49.5 | 49.6 | 1.7 | 3.4 | 38.3 | 48.8 | 19.1 | 1040 |
| Eucalyptus young | 1- 1 TO 12-31 | 365 | 20.4 | 49.5 | 49.6 | 1.7 | 3.4 | 38.3 | 48.8 | 19.1 | 1040 |
| Guava | 1- 1 TO 12-31 | 365 | 20.4 | 49.5 | 31.4 | 1.9 | 3.4 | 16.0 | 26.0 | 4.3 | 434 |
| Heliconia | 1- 1 TO 12-31 | 365 | 20.4 | 49.5 | 45.2 | 1.1 | 3.4 | 32.2 | 43.7 | 13.6 | 874 |
| Kikuyu Grass | 1- 1 TO 12-31 | 365 | 20.4 | 49.5 | 49.6 | 1.4 | 3.4 | 38.0 | 49.7 | 20.1 | 1032 |
| Lychee | 1- 1 TO 12-31 | 365 | 20.4 | 49.5 | 49.6 | 1.7 | 3.4 | 41.0 | 53.7 | 21.2 | 1113 |
| Macadamia nut | 1- 1 TO 12-31 | 365 | 20.4 | 49.5 | 45.3 | 1.1 | 3.4 | 32.3 | 44.2 | 13.6 | 877 |
| Ti | 1- 1 TO 12-31 | 365 | 20.4 | 49.5 | 45.9 | 1.2 | 3.4 | 33.1 | 44.6 | 15.2 | 899 |

Appendix 9.14: Waimea (Lalamilo Station) Seasonal Irrigation Requirements for Selected Crops

| **Crop Type** | **Irrigation Season** | **Length (day)** (day) | **Net Rainfall** (inch) | **Potential ET** (inch) | **Crop ET** (inch) | **Drainage** (inch) | **Runoff** (inch) | **Mean Irrigation Requirement** (inch) | **Maximum Irrigation Requirement** (inch) | **Minimum Irrigation Requirement** (inch) | **Mean Irrigation Requirement** (1000 gallons/acre) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alfalfa, initial | 11-15 TO 1-15 | 62 | 3.8 | 6.5 | 5.3 | 0.9 | 0.8 | 1.4 | 4.6 | 0.0 | 38 |
| Alfalfa, initial | 5-15 TO 7-15 | 62 | 1.3 | 9.9 | 7.9 | 0.0 | 0.0 | 5.4 | 6.4 | 3.5 | 147 |
| Alfalfa, ratoon | 11-15 TO 1-15 | 62 | 3.8 | 6.5 | 5.3 | 0.7 | 0.8 | 1.4 | 4.6 | 0.0 | 38 |
| Alfalfa, ratoon | 5-15 TO 7-15 | 62 | 1.3 | 9.9 | 7.9 | 0.0 | 0.0 | 6.0 | 7.1 | 4.5 | 163 |
| Banana, initial | 10- 1 TO 9-30 | 365 | 14.9 | 51.4 | 45.1 | 1.7 | 2.2 | 34.6 | 43.4 | 23.9 | 940 |
| Banana, initial | 5- 1 TO 4-30 | 365 | 14.9 | 51.4 | 40.9 | 0.4 | 2.2 | 28.4 | 37.9 | 16.5 | 771 |
| Banana, ratoon | 10- 1 TO 9-30 | 365 | 14.9 | 51.4 | 44.3 | 1.6 | 2.2 | 33.5 | 43.3 | 23.3 | 910 |
| Banana, ratoon | 5- 1 TO 4-30 | 365 | 14.9 | 51.4 | 40.0 | 0.3 | 2.2 | 27.5 | 37.0 | 16.5 | 747 |
| Cabbage | 11- 1 TO 1-31 | 92 | 5.6 | 10.0 | 8.2 | 1.3 | 1.2 | 3.3 | 5.8 | 1.2 | 90 |
| Cabbage | 5- 1 TO 7-31 | 92 | 2.0 | 14.6 | 12.1 | 0.0 | 0.0 | 9.1 | 10.7 | 7.2 | 247 |
| Cantaloupe | 10-15 TO 2-15 | 124 | 7.0 | 14.1 | 10.2 | 1.5 | 1.4 | 4.2 | 6.8 | 2.4 | 114 |
| Cantaloupe | 4-15 TO 8-15 | 123 | 3.0 | 19.5 | 14.2 | 0.1 | 0.1 | 10.5 | 12.4 | 8.5 | 285 |
| Dry Onion | 10-15 TO 2-15 | 124 | 7.0 | 14.1 | 12.7 | 1.1 | 1.4 | 6.1 | 9.5 | 3.0 | 166 |
| Dry Onion | 4-15 TO 8-15 | 123 | 3.0 | 19.5 | 18.1 | 0.1 | 0.1 | 14.6 | 16.8 | 12.8 | 396 |
| Eggplant | 10-15 TO 2-15 | 124 | 7.0 | 14.1 | 11.7 | 1.3 | 1.4 | 5.4 | 8.6 | 2.8 | 147 |
| Eggplant | 4-15 TO 8-15 | 123 | 3.0 | 19.5 | 16.7 | 0.1 | 0.1 | 13.2 | 15.5 | 11.0 | 358 |
| Ginger (AWD Potatoes) | 10- 1 TO 9-30 | 365 | 14.9 | 51.4 | 47.7 | 1.8 | 2.2 | 37.0 | 44.9 | 27.6 | 1005 |
| Ginger (AWD Potatoes) | 5- 1 TO 4-30 | 365 | 14.9 | 51.4 | 47.1 | 1.2 | 2.2 | 37.0 | 45.7 | 25.6 | 1005 |
| Lettuce | 11-15 TO 1-15 | 62 | 3.8 | 6.5 | 5.1 | 1.2 | 0.8 | 2.7 | 5.0 | 0.5 | 73 |
| Lettuce | 5-15 TO 7-15 | 62 | 1.3 | 9.9 | 7.7 | 0.0 | 0.0 | 6.8 | 8.1 | 5.3 | 185 |
| Other Melon | 10-15 TO 2-15 | 124 | 7.0 | 14.1 | 11.6 | 1.3 | 1.4 | 5.3 | 8.4 | 2.5 | 144 |
| Other Melon | 4-15 TO 8-15 | 123 | 3.0 | 19.5 | 16.6 | 0.1 | 0.0 | 13.1 | 15.2 | 11.2 | 356 |
| Pineapple, year 1 | 10- 1 TO 9-30 | 365 | 14.9 | 51.4 | 20.5 | 2.9 | 2.2 | 6.1 | 10.7 | 1.8 | 166 |
| Pineapple, year 1 | 5- 1 TO 4-30 | 365 | 14.9 | 51.4 | 21.6 | 2.6 | 2.2 | 9.1 | 13.3 | 4.6 | 247 |
| Pineapple, year 2 | 10- 1 TO 9-30 | 365 | 14.9 | 51.4 | 21.7 | 2.2 | 2.2 | 6.8 | 12.1 | 2.4 | 185 |
| Pineapple, year 2 | 5- 1 TO 4-30 | 365 | 14.9 | 51.4 | 22.6 | 1.8 | 2.2 | 9.3 | 13.3 | 3.7 | 253 |
| Pumpkin | 10-15 TO 2-15 | 124 | 7.0 | 14.1 | 11.3 | 1.3 | 1.4 | 5.0 | 8.1 | 2.5 | 136 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Pumpkin | 4-15 TO 8-15 | 123 | 3.0 | 19.5 | 16.1 | 0.1 | 0.1 | 12.6 | 14.5 | 10.6 | 342 |
| Seed, Corn | 10-15 TO 2-15 | 124 | 7.0 | 14.1 | 12.4 | 0.7 | 1.4 | 4.7 | 8.1 | 0.6 | 128 |
| Seed, Corn | 4-15 TO 8-15 | 123 | 3.0 | 19.5 | 17.8 | 0.1 | 0.1 | 13.4 | 15.0 | 11.2 | 364 |
| Sugarcane, New- year 1 | 10- 1 TO 9-30 | 365 | 14.9 | 51.4 | 52.6 | 1.3 | 2.2 | 40.1 | 50.0 | 28.6 | 1089 |
| Sugarcane, New- year 1 | 5- 1 TO 4-30 | 365 | 14.9 | 51.4 | 48.1 | 0.2 | 2.2 | 33.9 | 43.3 | 23.8 | 921 |
| Sugarcane, New- year 2 | 10- 1 TO 9-30 | 365 | 14.9 | 51.4 | 48.3 | 0.5 | 2.2 | 34.4 | 44.3 | 21.9 | 934 |
| Sugarcane, New- year 2 | 5- 1 TO 4-30 | 365 | 14.9 | 51.4 | 48.4 | 0.4 | 2.2 | 35.6 | 44.6 | 23.9 | 967 |
| Sugarcane, ratoon | 10- 1 TO 9-30 | 365 | 14.9 | 51.4 | 53.4 | 0.4 | 2.2 | 40.2 | 50.8 | 28.2 | 1092 |
| Sugarcane, ratoon | 5- 1 TO 4-30 | 365 | 14.9 | 51.4 | 52.9 | 0.2 | 2.2 | 40.7 | 50.3 | 30.3 | 1105 |
| Sweet potatoes | 10- 1 TO 2-28 | 151 | 8.2 | 17.8 | 16.1 | 1.0 | 1.6 | 8.7 | 13.4 | 4.7 | 236 |
| Sweet potatoes | 4- 1 TO 8-31 | 153 | 4.0 | 24.4 | 23.0 | 0.4 | 0.2 | 19.7 | 22.3 | 16.6 | 535 |
| Taro | 10- 1 TO 9-30 | 365 | 14.9 | 51.4 | 56.9 | 8.9 | 2.2 | 102.0 | 107.0 | 94.0 | 2770 |
| Taro | 5- 1 TO 4-30 | 365 | 14.9 | 51.4 | 56.4 | 8.8 | 2.2 | 101.0 | 107.0 | 97.0 | 2743 |
| Tomato | 10-15 TO 2-15 | 124 | 7.0 | 14.1 | 12.5 | 1.2 | 1.4 | 5.9 | 9.5 | 2.7 | 160 |
| Tomato | 4-15 TO 8-15 | 123 | 3.0 | 19.5 | 17.9 | 0.1 | 0.1 | 14.6 | 16.8 | 12.0 | 396 |
| Watermelon | 10-15 TO 2-15 | 124 | 7.0 | 14.1 | 11.5 | 1.3 | 1.4 | 5.3 | 8.4 | 2.7 | 144 |
| Watermelon | 4-15 TO 8-15 | 123 | 3.0 | 19.5 | 16.4 | 0.1 | 0.1 | 12.9 | 15.2 | 10.7 | 350 |
| Coffee | 1- 1 TO 12-31 | 365 | 14.7 | 51.4 | 47.5 | 0.4 | 2.2 | 41.3 | 51.5 | 27.8 | 1121 |
| Dendrobium, pot, micro-sprink | 1- 1 TO 12-31 | 365 | 14.7 | 51.4 | 51.5 | 4.8 | 2.2 | 51.8 | 58.6 | 42.9 | 1407 |
| Dendrobium, pot, nursery spray | 1- 1 TO 12-31 | 365 | 14.7 | 51.4 | 51.5 | 7.5 | 2.2 | 163 | 172 | 150 | 4426 |
| Draceana, pot micro-sprink | 1- 1 TO 12-31 | 365 | 14.7 | 51.4 | 51.5 | 4.2 | 2.2 | 51.2 | 57.5 | 43.7 | 1390 |
| Draceana, pot, nursery spray | 1- 1 TO 12-31 | 365 | 14.7 | 51.4 | 51.5 | 6.5 | 2.2 | 162 | 172 | 147 | 4399 |
| Eucaluptus closed canopy | 1- 1 TO 12-31 | 365 | 14.7 | 51.4 | 51.5 | 1.2 | 2.2 | 47.3 | 58.1 | 31.2 | 1284 |
| Eucalyptus young | 1- 1 TO 12-31 | 365 | 14.7 | 51.4 | 32.2 | 0.9 | 2.2 | 22.8 | 32.3 | 10.6 | 619 |
| Guava | 1- 1 TO 12-31 | 365 | 14.7 | 51.4 | 46.9 | 0.4 | 2.2 | 40.6 | 51.8 | 24.5 | 1102 |
| Heliconia | 1- 1 TO 12-31 | 365 | 14.7 | 51.4 | 51.5 | 0.3 | 2.2 | 46.1 | 56.6 | 29.7 | 1252 |
| Kikuyu Grass | 1- 1 TO 12-31 | 365 | 14.7 | 51.4 | 51.5 | 0.4 | 2.2 | 49.3 | 61.2 | 32.8 | 1339 |
| Lychee | 1- 1 TO 12-31 | 365 | 14.7 | 51.4 | 46.9 | 0.3 | 2.2 | 40.4 | 51.4 | 24.4 | 1097 |
| Macadamia nut | 1- 1 TO 12-31 | 365 | 14.7 | 51.4 | 47.5 | 0.5 | 2.2 | 41.4 | 52.5 | 26.3 | 1124 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ti | 1- 1 TO 12-31 | 365 | 14.7 | 51.4 | 51.5 | 0.3 | 2.2 | 46.1 | 56.2 | 29.7 | 1252 |

Appendix 9.15: Lower Hamakua (Paauilo Station) Seasonal Irrigation Requirements for Selected Crops

| **Crop Type** | **Irrigation Season** | **Length (day)** (day) | **Net Rainfall** (inch) | **Potential ET** (inch) | **Crop ET** (inch) | **Drainage** (inch) | **Runoff** (inch) | **Mean Irrigation Requirement** (inch) | **Maximum Irrigation Requirement** (inch) | **Minimum Irrigation Requirement** (inch) | **Mean Irrigation Requirement** (1000 gallons/acre) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alfalfa, initial | 11-15 TO 1-15 | 62 | 15.4 | 8.2 | 7.1 | 9.0 | 5.5 | 0.3 | 4.6 | 0.0 | 8 |
| Alfalfa, initial | 5-15 TO 7-15 | 62 | 8.1 | 13.4 | 11.3 | 1.8 | 0.9 | 4.5 | 10.0 | 0.0 | 122 |
| Alfalfa, ratoon | 11-15 TO 1-15 | 62 | 15.4 | 8.2 | 7.1 | 8.6 | 5.5 | 0.2 | 2.3 | 0.0 | 5 |
| Alfalfa, ratoon | 5-15 TO 7-15 | 62 | 8.1 | 13.4 | 11.3 | 1.5 | 0.9 | 4.3 | 9.5 | 0.0 | 117 |
| Banana, initial | 10- 1 TO 9-30 | 365 | 73.8 | 63.7 | 59.2 | 30.0 | 21.2 | 14.5 | 33.3 | 1.0 | 394 |
| Banana, initial | 5- 1 TO 4-30 | 365 | 73.8 | 63.7 | 54.2 | 25.9 | 21.2 | 7.5 | 26.6 | 0.0 | 204 |
| Banana, ratoon | 10- 1 TO 9-30 | 365 | 73.8 | 63.7 | 58.1 | 29.8 | 21.2 | 13.4 | 31.5 | 1.5 | 364 |
| Banana, ratoon | 5- 1 TO 4-30 | 365 | 73.8 | 63.7 | 53.4 | 25.6 | 21.2 | 6.5 | 26.0 | 0.0 | 177 |
| Cabbage | 11- 1 TO 1-31 | 92 | 22.0 | 12.5 | 10.9 | 12.7 | 7.5 | 1.5 | 5.3 | 0.0 | 41 |
| Cabbage | 5- 1 TO 7-31 | 92 | 13.9 | 19.5 | 17.1 | 3.8 | 2.0 | 6.5 | 13.9 | 0.4 | 177 |
| Cantaloupe | 10-15 TO 2-15 | 124 | 28.0 | 17.3 | 13.7 | 16.0 | 9.3 | 1.8 | 4.8 | 0.3 | 49 |
| Cantaloupe | 4-15 TO 8-15 | 123 | 20.9 | 25.4 | 20.1 | 7.1 | 4.0 | 6.3 | 15.3 | 0.7 | 171 |
| Dry Onion | 10-15 TO 2-15 | 124 | 28.0 | 17.3 | 16.2 | 14.6 | 9.3 | 2.7 | 8.1 | 0.8 | 73 |
| Dry Onion | 4-15 TO 8-15 | 123 | 20.9 | 25.4 | 24.4 | 6.3 | 4.0 | 9.8 | 20.4 | 1.8 | 266 |
| Eggplant | 10-15 TO 2-15 | 124 | 28.0 | 17.3 | 15.3 | 15.2 | 9.3 | 2.4 | 6.5 | 0.3 | 65 |
| Eggplant | 4-15 TO 8-15 | 123 | 20.9 | 25.4 | 23.0 | 6.6 | 4.0 | 8.6 | 18.9 | 1.8 | 234 |
| Ginger (AWD Potatoes) | 10- 1 TO 9-30 | 365 | 73.8 | 63.7 | 60.6 | 31.6 | 21.2 | 19.5 | 35.1 | 7.6 | 530 |
| Ginger (AWD Potatoes) | 5- 1 TO 4-30 | 365 | 73.8 | 63.7 | 59.6 | 30.8 | 21.2 | 19.3 | 37.0 | 5.7 | 524 |
| Lettuce | 11-15 TO 1-15 | 62 | 15.4 | 8.2 | 7.0 | 9.7 | 5.5 | 1.4 | 4.7 | 0.0 | 38 |
| Lettuce | 5-15 TO 7-15 | 62 | 8.1 | 13.4 | 11.1 | 2.1 | 0.9 | 5.7 | 11.1 | 0.5 | 155 |
| Other Melon | 10-15 TO 2-15 | 124 | 28.0 | 17.3 | 15.2 | 15.2 | 9.3 | 2.5 | 6.5 | 0.4 | 68 |
| Other Melon | 4-15 TO 8-15 | 123 | 20.9 | 25.4 | 22.9 | 6.6 | 2.0 | 8.6 | 18.1 | 1.7 | 234 |
| Pineapple, year 1 | 10- 1 TO 9-30 | 365 | 73.8 | 63.7 | 35.1 | 40.3 | 21.2 | 0.9 | 4.8 | 0.0 | 24 |
| Pineapple, year 1 | 5- 1 TO 4-30 | 365 | 73.8 | 63.7 | 37.2 | 39.4 | 21.2 | 3.6 | 12.7 | 0.0 | 98 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Pineapple, year 2 | 10- 1 TO 9-30 | 365 | 73.8 | 63.7 | 37.0 | 38.2 | 21.2 | 1.0 | 6.0 | 0.0 | 27 |
| Pineapple, year 2 | 5- 1 TO 4-30 | 365 | 73.8 | 63.7 | 38.4 | 37.3 | 21.2 | 2.8 | 11.0 | 0.0 | 76 |
| Pumpkin | 10-15 TO 2-15 | 124 | 28.0 | 17.3 | 14.9 | 15.4 | 9.3 | 2.2 | 6.1 | 0.4 | 60 |
| Pumpkin | 4-15 TO 8-15 | 123 | 20.9 | 25.4 | 22.2 | 6.8 | 4.0 | 8.0 | 18.0 | 1.3 | 217 |
| Seed, Corn | 10-15 TO 2-15 | 123 | 20.9 | 25.4 | 22.2 | 6.8 | 4.0 | 8.0 | 18.0 | 1.3 | 43 |
| Seed, Corn | 4-15 TO 8-15 | 124 | 28.0 | 17.3 | 16.2 | 13.5 | 9.3 | 1.6 | 6.5 | 0.0 | 247 |
| Sugarcane, New- year 1 | 10- 1 TO 9-30 | 365 | 73.8 | 63.7 | 67.7 | 26.7 | 21.2 | 19.1 | 39.1 | 2.0 | 519 |
| Sugarcane, New- year 1 | 5- 1 TO 4-30 | 365 | 73.8 | 63.7 | 62.0 | 21.6 | 21.2 | 10.4 | 31.9 | 0.0 | 282 |
| Sugarcane, New- year 2 | 10- 1 TO 9-30 | 365 | 73.8 | 63.7 | 62.0 | 24.5 | 21.2 | 11.4 | 29.9 | 0.0 | 310 |
| Sugarcane, New- year 2 | 5- 1 TO 4-30 | 365 | 73.8 | 63.7 | 61.6 | 23.6 | 21.2 | 13.7 | 36.6 | 0.0 | 372 |
| Sugarcane, ratoon | 10- 1 TO 9-30 | 365 | 73.8 | 63.7 | 68.0 | 22.4 | 21.2 | 16.0 | 36.4 | 1.9 | 434 |
| Sugarcane, ratoon | 5- 1 TO 4-30 | 365 | 73.8 | 63.7 | 66.7 | 21.0 | 21.2 | 16.5 | 42.3 | 0.0 | 448 |
| Sweet potatoes | 10- 1 TO 2-28 | 151 | 33.3 | 21.7 | 20.6 | 15.8 | 10.6 | 3.3 | 8.7 | 0.0 | 90 |
| Sweet potatoes | 4- 1 TO 8-31 | 153 | 28.1 | 31.0 | 30.8 | 9.3 | 6.6 | 12.6 | 26.2 | 2.8 | 342 |
| Taro | 10- 1 TO 9-30 | 365 | 73.8 | 63.7 | 70.6 | 51.5 | 21.2 | 96.9 | 114.5 | 79.3 | 2631 |
| Taro | 5- 1 TO 4-30 | 365 | 73.8 | 63.7 | 69.7 | 51.4 | 21.2 | 95.4 | 111.6 | 72.6 | 2591 |
| Tomato | 10-15 TO 2-15 | 124 | 28.0 | 17.3 | 16.2 | 14.6 | 9.3 | 2.6 | 7.1 | 0.3 | 71 |
| Tomato | 4-15 TO 8-15 | 123 | 20.9 | 25.4 | 24.5 | 6.3 | 4.0 | 10.0 | 20.4 | 2.1 | 272 |
| Watermelon | 10-15 TO 2-15 | 124 | 28.0 | 17.3 | 15.0 | 15.4 | 9.4 | 2.4 | 6.6 | 0.4 | 65 |
| Watermelon | 4-15 TO 8-15 | 123 | 20.9 | 25.4 | 22.5 | 6.7 | 4.0 | 8.4 | 18.3 | 1.4 | 228 |
| Coffee | 1- 1 TO 12-31 | 365 | 73.7 | 63.7 | 59.9 | 26.7 | 21.2 | 16.0 | 40.0 | 1.1 | 434 |
| Dendrobium, pot, micro-sprink | 1- 1 TO 12-31 | 365 | 73.7 | 63.7 | 63.7 | 39 | 21.2 | 35.8 | 51.5 | 21.2 | 972 |
| Dendrobium, pot, nursery spray | 1- 1 TO 12-31 | 365 | 73.7 | 63.7 | 63.7 | 44.3 | 21.2 | 149 | 189 | 115 | 4046 |
| Draceana, pot micro-sprink | 1- 1 TO 12-31 | 365 | 73.7 | 63.7 | 63.7 | 38.7 | 21.2 | 35.4 | 55.8 | 18.3 | 961 |
| Draceana, pot, nursery spray | 1- 1 TO 12-31 | 365 | 73.7 | 63.7 | 63.7 | 42 | 21.2 | 144 | 186 | 107 | 3910 |
| Eucaluptus closed canopy | 1- 1 TO 12-31 | 365 | 73.7 | 63.7 | 63.7 | 24.5 | 21.2 | 18.1 | 46.0 | 0.0 | 491 |
| Eucalyptus young | 1- 1 TO 12-31 | 365 | 73.7 | 63.7 | 44.9 | 32.9 | 21.2 | 5.0 | 19.4 | 0.0 | 136 |
| Guava | 1- 1 TO 12-31 | 365 | 73.7 | 63.7 | 58.9 | 25.5 | 21.2 | 13.3 | 36.2 | 1.3 | 361 |
| Heliconia | 1- 1 TO 12-31 | 365 | 73.7 | 63.7 | 63.7 | 24.8 | 21.2 | 18.4 | 43.6 | 2.2 | 500 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Kikuyu Grass | 1- 1 TO 12-31 | 365 | 73.7 | 63.7 | 63.7 | 25.8 | 21.2 | 21.0 | 49.5 | 2.4 | 570 |
| Lychee | 1- 1 TO 12-31 | 365 | 73.7 | 63.7 | 59.0 | 25.2 | 21.2 | 13.1 | 35.3 | 0.0 | 356 |
| Macadamia nut | 1- 1 TO 12-31 | 365 | 73.7 | 63.7 | 59.9 | 25.6 | 21.2 | 14.7 | 37.8 | 0.0 | 399 |
| Ti | 1- 1 TO 12-31 | 365 | 73.7 | 63.7 | 63.7 | 24.8 | 21.2 | 18.4 | 43.6 | 2.2 | 500 |

Appendix 9.16: Conceptual Model and Scoring Indicators for Irrigation System Assessment

| **Conceptual Indicators** | | **Empirical Indicators** |
|---|---|---|
| **1.0** | ***Irrigation Water Supply:*** System-level availability and reliability of water and diversion of water over time. | |
| a. | average daily supply* | Avg. water diverted per cultivated acre |
| b. | diversion capacity* | Water diversion capacity per irrigable acre |
| | | % water diverted relative to water diversion capacity |
| c. | seasonal variability (relative wet:dry) in water supply | Ratio of wet to dry season water diversions |
| d. | interannual variability (wet:dry year) in water supply | Qualitative assessment of reliability: no. of sources, groundwater vs. surface sources, elevation and length of stream sources |
| **2.0** | ***Irrigation Infrastructure and Water Delivery:*** Availability, condition, and adequacy of system- and farm-level facilities, and adequacy of farm water deliveries. | |
| a. | system water capture and intake infrastructure | *Problems reported by system managers:* |
| | | - intake clogging |
| | | - difficulty accessing infrastructure |
| | | - inadequate control structures |
| b. | system water conveyances and system water control structures | % Irrigable acres within 0.25 miles from conveyance |
| | | *Problems reported by system managers:* |
| | | - cracked or leaking infrastructure |
| | | - blockages of conveyances or structures |
| | | - siltation/rocks in conveyances or structures |
| | | - inadequate control structures |
| | | - inadequate water head or pressure |
| c. | system water reservoirs (short-term storage only) | System storage capacity per irrigable acre |
| | | Problems reported by system managers on inadequate storage |

| Conceptual Indicators | | Empirical Indicators |
|---|---|---|
| d. | farm water distribution and field application facilities | *Problems reported by system managers:* |
| | | - leaks |
| | | - inadequate control of water flows |
| | | - inadequate water storage |
| e. | average water deliveries to farms* | % water diverted actually delivered |
| f. | adequacy of farm water supplies relative to demand | Farmer assessments on adequacy of farm water supply |
| | | Presence of an alternative source of water supply |
| **3.0** | ***Irrigation System Management:*** Effectiveness of system management and quality of irrigation service. | |
| a. | system management personnel | *Problems reported by system managers:* |
| | | - staff turnover |
| | | - inadequately skilled staff |
| b. | system equipment for operations and maintenance (O&M) | Problems reported by system managers on inadequate equipment |
| c. | management systems including water planning and monitoring | Quantitative recorded water measures at system intake or major sections/conveyances and at farm level |
| | | Regularity (seasonal, emergency only, none) of planning for water allocation and delivery |
| | | Farmer assessments on responsiveness of management |
| d. | financial resources for system O&M* | Cultivated area / $100,000 O&M budget |
| | | Irrigable area / $100,000 O&M budget |
| | | Problems reported by system managers on financial security |
| e. | financial resources for system capital improvements | Qualitative assessment on no. and size of capital improvement projects over last (approx.) 5 years |
| f. | farmer participation in system management | Degree of involvement by farmer advisory group in managing system |
| | | Problems reported by system managers on lack of cooperation by irrigators |
| | | Presence of water user organization and farmer membership |
| | | Presence of other organizations involved with irrigation |
| g. | farmer satisfaction with irrigation service | Farmer assessments on fair and equitable water distribution |

| Conceptual Indicators | | Empirical Indicators |
|---|---|---|
| | | Farmer assessments on system customer service |
| **4.0** | ***Land Resources:*** Agricultural potential of lands and climatic resources within the system area. | |
| a. | soil productivity for agriculture | % Irrigable area rate Prime in ALISH (Agricultural Lands of Importance to the State of Hawaii) system |
| b. | soil and other land limitations for agricultural uses | % Irrigable acres by Land Capability Classes (LCC) for non-irrigated conditions |
| | | Qualitative assessment on availability of LCC data for irrigated conditions and average system increase in LCC class with irrigation |
| | | *Problems reported by system manager and farmers:* |
| | | - erosion |
| | | - drainage |
| c. | climatic factors affecting net demand for irrigation water (e.g., rainfall, solar radiation) | Irrigation water requirement for reference crop (net of effective rainfall) |
| **5.0** | ***Farm Infrastructure and Institutions***<br>Non-water facilities and conditions affecting farm viability and profitability. | |
| a/d. | agricultural property development including farm lots, field boundaries, farm infrastructure including fences/other security measures | % system area with farm lots and field boundaries |
| | | % farmers taking security measures relative to reported theft and invasive animal problems. |
| b. | security of farm land tenure | % farmers with owned land, government lease or long-term private lease |
| | | % system area in Hawaiian Homes land |
| | | Problems reported by system managers and farmers involving land deeds or lease claims |
| c. | public infrastructure including roads, electricity | Farmer assessments on quality of transportation services in community |
| | | Farmer assessments on quality of road conditions |
| e. | farm production costs, particularly purchased inputs | Farmer reported problems in procuring farm inputs |
| f. | farm revenues, particularly marketing outlets and sales | % farm output exported outside of Hawaii |

| Conceptual Indicators | | Empirical Indicators |
|---|---|---|
| | | Farmer reported problems in marketing farm outputs |
| **6.0** | ***Non-Agricultural Community:*** Relations between the irrigation system/farmers and non-farm residents in the surrounding area. | |
| a. | conflicts for farms including theft and vandalism | *Problems reported by system managers and farmers:* |
| | | - farm thefts |
| | | - farm vandalism |
| | | - trespassing on farmlands |
| | | - lack of communication, awareness, involvement by non-ag community |
| b. | conflicts for non-farm residents including noise and smells | Problems with neighbor complaints reported by system managers and farmers |
| c. | pressure to develop irrigation system lands for non-agricultural uses | System managers and farmer assessments on likelihood of continued irrigated ag in area through 2030 |
| | | System managers assessment on percentage system area remaining in ag for next 25 years |
| d. | protections to preserve irrigation system lands for agricultural use | Farmer assessments on percentage of own farmed area remaining in ag for next 25 years |
| | | Farmer assessments on strength of community commitment to maintaining ag |
| 7.0 | ***Environmental Problems and Limitations:*** Water, land and other biophysical conditions negatively impacting irrigated agriculture. | |
| a. | water pollution or other water quality problems | System managers and farmer reported problems with water quality or water pollution |
| b. | air quality | System managers and farmer reported problems with air quality |
| c. | endangered species | System managers and farmer reported problems with endangered species |
| d. | invasive species | System managers and farmer reported problems with invasive species |

| Conceptual Indicators | | Empirical Indicators |
|---|---|---|
| e. | water rights disputes or conflicts | System managers and farmer reported problems with pre-existing water rights |
| f. | disputed farmland claims or restrictions on deed or lease | System managers and farmer reported problems with environmental restrictions on land deeds or leases |

Note: asterisk (*) denotes factor accounts for differences in system size (e.g., per ac. basis)

Appendix 9.17: Criteria for Scoring Empirical Indicators

| Indicator Group | Indicator Numbers | Coding Definition | Numeric Rating |
|---|---|---|---|
| *Problem Type:* | n/a | Some indicators are in a composite consists of widespread, severity, and frequency aspects. The numeric rating was obtain by averaging the three composite's components (widespread, frequency, and severity) | |
| Widespread (superintendent) | 2, 2b, 2d, 4b, 6, 6b,<br>3, 3b, 3d, 3f,<br>5b, 7, 7b, 7c, 7d,<br>7e, 7f | H= Problem widespread throughout system, common and/or involves a majority (>50%) of farmers or organized groups, entire communities<br>M= In between H and L involving only certain situations (e.g. people and places)<br>L= Few of isolated, incidental situations<br>None | 0<br>3<br>6<br>10 |
| Widespread (farmer) | 6a, 6b, 7a, 7b, 7c, 7d, 7e, 7f | H= Problem for most of farm (>75%) of farm<br>M= In between H and L<br>L= Problem present only in few situations<br>None | 0<br>3<br>6<br>10 |
| Severity | 2, 2b, 2c, 2d, 4b, 6, 6b, 3, 3b, 3d, 3f, 5b, 7, 7b, 7c, 7d, 7e, 7f | H= Serious/major disruptions of irrigation O&M and/or involves many (>25%) of farmers<br>M= Moderate problem that hinders irrigation O&M<br>L= Minor concern with small (<10%) impacts or for infrastructure just a maintenance issue<br>None | 0<br>3<br>6<br>10 |
| Frequency | 2, 2b, 2c, 2d, 4b, 6, 6b, 3, 3b, 3f, 3d, 5b, 7, 7b, 7c, 7d, 7e, 7f | H= Continuous/monthly or more<br>M= In between H and L, or only for specific events<br>L= Isolated or rare occurrences, or happens seldom<br>None | 0<br>3<br>6<br>10 |
| *5 Part Ratings* | 3g, 5b, 5c, 6c, 6d | Average farmer (numeric) rating rounded to nearest integer | |

| | | | |
|---|---|---|---|
| | | H= very strong/very good/highly likely/all or nearly all<br>HM= strong/good/likely/most areas<br>M= fairly strong//fairly good/somewhat likely/at least half<br>L= neutral/not so good/not likely/less than half<br>O= no commitment/bad/never/little or none | 10<br>7<br>5<br>3<br>0 |
| Positive/ Negative Responses | 2f, 3c, 3f, 3g, 5b | Number of farmers who responded positively<br>H= all or almost all say "yes" or majority (>75%)<br>M= more than 1 says "yes"<br>L= more than 1 says "no" or "not sure" | <br>10<br>5<br>0 |
| Water Supply | 1a, 1b | Need average 7,500 gad (midpoint between high-use crop like sugar, banana and moderate-use crop). Data value X gal/ac/day. Coding= X/750, round to nearest integer with max 10 points. Example Molokai IS. | 1,090/750= 1.4 ~ 1 |
| Reservoir Storage | 2b | Full storage ~ 2 month (60 days) – 7,500 x 60=540,000 ~ 0.5 MGD<br>Coding: Storage/(ac x 0.5) x 10 (round to nearest integer).<br>Example Waimanalo IS. | 60/(500 x 0.5) = 0.24 x 10 = 2.4 ~ 2 |
| O&M Funding | 3d | Need $100,000 for 500 ac. Formula: actual ac./(500 x (budget/100,000)) x 10 round to nearest integer. Example Waimanalo IS (700 ac. with $300,000). | [700/(500 x 3)] x 10 = 4.6 ~ 5 |
| Proportions | 1b, 1c, 2, 2d, 2e, 4, 4c, 5, 5b, 5e | Scale dividing by 10 and rounding to nearest integer; can be an aggregate farmer average (where applicable)<br>Example 65:35 seasonality of water supply.<br>Example 95% response.<br>Note: For export sales, a zero score is representative of all farmers being local suppliers. | <br><br>65/10=6.5~7<br>9.5/10 ~ 10 |
| LCC<br><br><br><br>With Rehabilitation | 4b<br><br><br><br>Irrigated LCC | H= majority of acreage in system is represented, in all major sections<br>M= more than 25%, but unrepresentative<br>L= less than 25% overall or significant proportions missing<br><br>H= average change by 2 classes into classes IV or higher<br>M= average change by 1 class into class IV or higher<br>L= improvements minor, little or no increase in class I or II with the addition of irrigation | 10<br>5<br>0<br><br>10<br>5<br>0 |

| | | | |
|---|---|---|---|
| Check Boxes | 3c, 5d, 5e | H= majority of farmers have big (more then 3 checks) problems<br>M= In between (1 to 2 checks)<br>L= Most farmers have no problems | 0<br>5<br>10 |
| Water Planning<br><br><br>Water Supply | 3c<br><br><br>1d | H= seasonal, more frequent, and have plan to allocate water<br>M= emergency water allocation plan only or plan for drought conditions<br>L= no real planning<br>H= mountain streams, multiple sources, direct use of GW to supplement irrigation system (> 80%)<br>M= In between H and L<br>L= Short length with only single source, flashy streams, at low elevation, <50%, if water restriction were enforced more than once in the last ten years | 10<br>5<br>0<br>10<br><br>5<br><br>0 |
| Financial | 3e | H= more than 1 major improvement<br>M= 1 major project and or several minor (smaller) projects<br>L= none or sporadic deferred maintenance | 10<br>5<br>0 |
| Water Advice | 3f | H= formal farmer organization with regular meetings that assume system responsibility<br>HM= ongoing continuous meetings but irregular or informal<br>M= There exists an organization but irregular or informal<br>L= Advice with little or no authority, for emergencies only, small group<br>None= No organization, individual farmers meet but not a group | 10<br>7<br>5<br>3<br>0 |

Appendix 9.18: Studied System Indicator Ratings without System Rehabilitation

| **Ind. Code** | **Empirical Indicator** | **East Kauai** | **Kauai Coffee** | **Kekaha** | **Hamakua** | **Molokai** | **Upcountry Maui** | **West Maui** | **Waimea** | **Waiahole** | **Waimanalo** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1.0** | ***Irrigation Water Supply*** | | | | | | | | | | |
| 1d | Historical dry year record water diversion | 10 | 5 | 10 | 5 | 5 | 0 | 5 | 10 | 5 | 5 |
| 1b | Water diversion capacity per irrigable acre | 2 | 10 | 10 | 5 | 1 | 10 | 10 | 4 | 10 | 1 |
| 1b | % water diverted to water diversion capacity | 6 | 7 | 4 | 6 | 10 | 10 | 5 | 3 | 3 | 2 |
| 1c | Ratio of wet to dry season water diversions | 10 | 8 | 6 | 5 | 3 | 3 | 5 | 10 | 8 | 8 |
| 1a | Avg. water diverted per cultivated acre | 6 | 9 | 4 | 10 | 1 | 10 | 10 | 10 | 7 | 1 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **2.0** | ***Irrigation Infrastructure and Water Delivery*** | | | | | | | | | | |
| 2f | Adequacy of farm water supply | 7 | 5 | 10 | 8 | 10 | 6 | 5 | 8 | 10 | 3 |
| 2f | Presence of alternative source of water supply | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| 2b | Cracked or leaking infrastructure | 2 | 8 | 4 | 10 | 10 | 10 | 5 | 9 | 9 | 8 |
| 2b | Siltation/Rocks | 4 | 5 | 8 | 10 | 5 | 3 | 3 | 9 | 10 | 9 |
| 2b | Blockages of conveyances | 3 | 8 | 10 | 10 | 10 | 5 | 6 | 9 | 10 | 9 |
| 2a | Inadequate control structures (system) | 4 | 10 | 10 | 10 | 10 | 9 | 9 | 10 | 10 | 10 |
| 2b | Inadequate head or pressure | 7 | 10 | 10 | 10 | 6 | 10 | 5 | 10 | 9 | 8 |
| 2e | % water diverted actually delivered | 4 | 9 | 10 | 5 | 9 | 10 | 5 | 2 | 6 | 5 |
| 2a | Intake clogging | 4 | 2 | 5 | 8 | 8 | 3 | 3 | 10 | 8 | 10 |
| 2a | Access difficulty | 2 | 10 | 8 | 2 | 10 | 4 | 10 | 10 | 10 | 8 |
| 2a | Inadequate control structures (system) | 4 | 10 | 10 | 10 | 10 | 9 | 9 | 10 | 10 | 10 |
| 2a | % irrigable acre within 0.25 miles from conveyances | 2 | 4 | 2 | 3 | 3 | 4 | 2 | 2 | 7 | 9 |
| 2c | Inadequate storage | 10 | 9 | 10 | 10 | 10 | 8 | 10 | 10 | 9 | 10 |
| 2d | Leaks | 10 | 4 | 9 | 9 | 10 | 10 | 9 | 10 | 7 | 9 |
| 2d | Inadequate control of water flows | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 9 |
| 2d | Inadequate water storage | 10 | 9 | 10 | 9 | 10 | 10 | 10 | 10 | 5 | 10 |
| **3.0** | ***Land Resources*** | | | | | | | | | | |
| 4c | Water requirement for reference crop | 1 | 4 | 6 | 2 | 10 | 4 | 9 | 6 | 5 | 2 |
| 4a | % Irrigable area rate prime by ALISH | 8 | 9 | 8 | 7 | 8 | 0 | 7 | 8 | 8 | 7 |
| 4b | % Irrigable acres by LCC | 9 | 9 | 5 | 7 | 7 | 9 | 6 | 10 | 10 | 10 |
| 4b | Qualitative assessment on availability of LCC | 5 | 6 | 4 | 7 | 4 | 7 | 5 | 6 | 8 | 5 |
| 4b | Erosion (system) | 10 | 10 | 8 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4b | Erosion (farm) | 10 | 10 | 4 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| 4b | Drainage (system) | 9 | 10 | 10 | 8 | 9 | 8 | 3 | 10 | 10 | 10 |
| 4b | Drainage (farm) | 10 | 10 | 10 | 4 | 7 | 8 | 3 | 10 | 10 | 10 |
| **6.0** | ***Farm Infrastructure and Institutions*** | | | | | | | | | | |
| 5e | Export sales | 2 | 5 | 5 | 0 | 6 | 3 | 5 | 3 | 0 | 3 |
| 5e | Output marketing problems | 8 | 5 | 3 | 5 | 0 | 6 | 5 | 7 | 5 | 5 |
| 5d | Input marketing problems | 5 | 5 | 3 | 3 | 3 | 6 | 5 | 3 | 7 | 5 |
| 5b | Security of Land Tenure | 7 | 10 | 0 | 5 | 7 | 8 | 5 | 5 | 7 | 0 |
| 5b | % system area in Hawaiian home land | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 2 | 0 |
| 5b | Land deeds, or Restriction | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| 5a | Farmstead Development | 5 | 10 | 6 | 10 | 5 | 10 | 10 | 10 | 10 | 10 |
| 5a | Deg. Of farm security for the irrigation system | 8 | 5 | 7 | 5 | 3 | 5 | 5 | 8 | 0 | 8 |
| 5c | Transportation (a) | 6 | 5 | 5 | 4 | 2 | 8 | 5 | 6 | 6 | 5 |
| 5c | Transportation(b) | 7 | 5 | 8 | 4 | 8 | 6 | 5 | 6 | 5 | 5 |
| **7.0** | ***Environmental Problems and Limitations*** | | | | | | | | | | |
| 7e | Pre-existing water rights (system) | 9 | 10 | 10 | 10 | 2 | 10 | 6 | 10 | 10 | 10 |
| 7e | Pre-existing water rights (farm) | 9 | 10 | 10 | 10 | 10 | 10 | 6 | 10 | 10 | 10 |
| 7a | Water quality or pollution (b) (system) | 9 | 9 | 3 | 10 | 10 | 5 | 5 | 9 | 10 | 10 |
| 7a | Water quality or pollution (farm) | 10 | 10 | 5 | 8 | 7 | 10 | 7 | 10 | 10 | 9 |
| 7d | Invasive species (system) | 6 | 2 | 9 | 10 | 8 | 4 | 4 | 10 | 10 | 9 |
| 7d | Invasive species (farm) | 5 | 2 | 9 | 1 | 2 | 10 | 4 | 10 | 9 | 10 |
| 7b | Air quality (system) | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| 7b | Air Quality (farm) | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 9 | 10 |
| 7c | Endangered species (system) | 8 | 8 | 9 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| 7c | Endangered species (farm) | 7 | 8 | 10 | 10 | 10 | 9 | 10 | 10 | 10 | 10 |
| 7f | Land claim limitations (system) | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| 7f | Land claim limitations | 10 | 10 | 8 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | (farm) | | | | | | | | | | |
| **5.0** | ***Irrigation System Management*** | | | | | | | | | | |
| 3c | Quantitative recorded water measures | 8 | 10 | 5 | 5 | 5 | 10 | 10 | 10 | 5 | 5 |
| 3c | Written seasonal plan for water allocation and delivery | 10 | 10 | 0 | 0 | 10 | 10 | 10 | 10 | 10 | 10 |
| 3c | Farmer assessments on responsiveness of mgt. | 10 | 5 | 5 | 3 | 10 | 7 | 5 | 8 | 5 | 8 |
| 3e | System Improvement | 5 | 4 | 8 | 8 | 10 | 10 | 5 | 5 | 3 | 10 |
| 3d | O&M budget/cultivated area | 3 | 5 | 2 | 10 | 5 | 10 | 5 | 10 | 6 | 10 |
| 3d | O&M budget/irrigable area | 1 | 5 | 2 | 5 | 2 | 10 | 5 | 10 | 4 | 10 |
| 3d | Financial Security | 4 | 10 | 10 | 8 | 0 | 10 | 10 | 10 | 7 | 8 |
| 3f | Deg involved by farmer advocate group | 7 | 5 | 10 | 10 | 7 | 5 | 5 | 8 | 5 | 5 |
| 3f | Lack of cooperation by irrigators | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| 3f | Water use org. & membership | 10 | 5 | 10 | 10 | 10 | 1 | 5 | 10 | 0 | 0 |
| 3f | Other org. for irrigation | 7 | 5 | 0 | 5 | 10 | 9 | 5 | 7 | 3 | 10 |
| 3a | Staff turnover | 10 | 8 | 10 | 10 | 10 | 10 | 9 | 10 | 10 | 8 |
| 3a | Inadequate skilled staff | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 8 |
| 3b | Inadequate equipment | 10 | 8 | 10 | 8 | 0 | 10 | 5 | 9 | 4 | 10 |
| 3g | Fair equitable water distribution | 7 | 5 | 10 | 10 | 10 | 9 | 5 | 8 | 10 | 5 |
| 3g | Customer Service | 8 | 5 | 10 | 9 | 9 | 9 | 5 | 6 | 6 | 8 |
| **4.0** | ***Non-Agricultural Community*** | | | | | | | | | | |
| 6d | Future Farm Area | 8 | 5 | 10 | 9 | 6 | 5 | 7 | 5 | 8 | 5 |
| 6d | Community commitment to agriculture | 4 | 5 | 10 | 9 | 9 | 5 | 5 | 3 | 8 | 3 |
| 6c | Prospect for Ag. In future (system) | 10 | 5 | 10 | 7 | 9 | 5 | 7 | 7 | 7 | 8 |
| 6c | Prospect for Ag. In future (farm) | 8 | 5 | 9 | 8 | 8 | 5 | 7 | 6 | 7 | 8 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 6c | Future Irrigated Area | 7 | 5 | 7 | 7 | 10 | 5 | 3 | 5 | 10 | 10 |
| 6b | Neighbor complaints (system) | 7 | 10 | 10 | 10 | 10 | 6 | 10 | 10 | 10 | 10 |
| 6b | Neighbor complaints (farm) | 8 | 10 | 7 | 10 | 8 | 9 | 10 | 10 | 8 | 10 |
| 6a | Farm theft (system) | 7 | 0 | 0 | 9 | 10 | 10 | 1 | 8 | 10 | 3 |
| 6a | Farm theft (Farm) | 9 | 0 | 6 | 2 | 8 | 10 | 1 | 10 | 9 | 9 |
| 6a | Vandalism | 6 | 10 | 0 | 10 | 10 | 10 | 9 | 9 | 10 | 10 |
| 6a | Vandalism | 8 | 10 | 6 | 8 | 6 | 10 | 9 | 10 | 10 | 10 |
| 6a | Trespassing | 7 | 10 | 8 | 10 | 10 | 10 | 2 | 10 | 10 | 10 |
| 6a | Trespassing | 9 | 10 | 2 | 9 | 9 | 10 | 10 | 9 | 9 | 10 |
| 6a | Lack of Communication & awareness | 10 | 10 | 3 | 10 | 10 | 6 | 10 | 9 | 10 | 10 |
| 6a | Lack of Communication & awareness | 9 | 10 | 10 | 1 | 7 | 6 | 10 | 10 | 2 | 10 |

Appendix 9.19: Final Weights for Irrigation Assessment Model

| **Component/Indicator**<br>(sr=system manager response, fr=farmer responses) | **Mean Panel Weight** |
|---|---|
| ***1. Irrigation Water Supply*** | |
| Historical dry year record water diversion | 28 |
| Water diversion capacity per irrigable acre | 20 |
| % water diverted to water diversion capacity | 12 |
| Ratio of wet to dry season water diversions | 16 |
| Average water diverted per cultivated acre | 25 |
| **Max component points** | **31** |
| ***2. Irrigation Infrastructure and Water Delivery*** | |
| Adequacy of farm water supply | 22 |
| Alternative source of water supply | 13 |
| Cracked or leaking conveyance/control structures | 8 |
| Siltation/rocks in conveyances/control structures | 5 |
| Blockage of conveyances | 4 |
| Inadequate control structures | 5 |
| Inadequate head or pressure in system | 4 |
| % water diverted actually delivered | 6 |
| Intake clogging | 4 |
| Difficulty accessing water capture facility/intake | 3 |
| Inadequate control structures at water capture facility/intake | 3 |
| % irrigable acre within 0.25 miles from conveyance | 3 |
| Inadequate reservoir storage | 7 |
| Leaks in farm water facilities | 5 |
| Inadequate control of farm water flows | 3 |
| Inadequate farm water storage | 5 |
| **Max component points** | **19** |
| ***3. Land Resources*** | |
| Crop demand for irrigation water | 46 |
| % irrigable area rate prime in ALISH | 25 |
| % irrigable acres by LCC | 9 |
| Ratio LCC for irrigated: non-irrigated conditions | 4 |
| Erosion (sr) | 4 |
| Erosion (fr) | 5 |
| Drainage (sr) | 3 |
| Drainage (fr) | 3 |
| **Max component points** | **21** |
| ***4. Farm Infrastructure and Institutions*** | |
| Export sales | 24 |
| Output marketing problems | 19 |
| Input marketing problems | 11 |
| Security of land tenure | 14 |
| Native Hawaiian farmsteads | 5 |
| Land deeds or lease claims | 4 |

| **Component/Indicator** (sr=system manager response, fr=farmer responses) | **Mean Panel Weight** |
|---|---|
| Farmstead development | 8 |
| Degree or extent of farm security for the irrigation system | 4 |
| Transportation service in community | 8 |
| Road quality assessment | 4 |
| **Max component points** | **7** |
| ***5. Environmental Problems and Limitations*** | |
| Pre-existing water rights (sr) | 21 |
| Pre-existing water rights (fr) | 23 |
| Water quality or pollution (sr) | 11 |
| Water quality or pollution (fr) | 11 |
| Invasive species (fr) | 8 |
| Invasive species (sr) | 4 |
| Air quality (sr) | 3 |
| Air quality (fr) | 2 |
| Endangered species (sr) | 4 |
| Endangered species (fr) | 4 |
| Land claim limitations (fr) | 5 |
| Land claim limitations (sr) | 3 |
| **Max component points** | **6** |
| ***6. Irrigation System Management*** | |
| Quantitative recorded water measures at farm level | 11 |
| Regularity of planning for water allocation and delivery | 9 |
| Farmer assessments on responsiveness of management | 6 |
| Financial resources for system capital improvements | 14 |
| Cultivated area / $100,000 O&M budget | 5 |
| Irrigable area / $100,000 O&M budget | 5 |
| Financial security | 5 |
| Degree of involvement by farmer advisory group | 7 |
| Lack of cooperation by irrigators | 3 |
| Water user org. and membership in org. | 5 |
| Other org. for irrigations | 3 |
| System staff turnover | 3 |
| Inadequate skilled system staff | 4 |
| Inadequate equipment for system O&M | 6 |
| Fair equitable water distribution | 9 |
| Customer service | 5 |
| **Max component points** | **9** |
| ***7. Non-Agricultural Community*** | |
| Future preservation of farm area | 16 |
| Community commitment to ag. | 13 |
| Prospect for ag. in future (sr) | 13 |
| Prospect for ag. in future (fr) | 12 |

| **Component/Indicator**<br>(sr=system manager response, fr=farmer responses) | **Mean Panel Weight** |
|---|---|
| Future for irrigated area (sr) | 8 |
| Neighbor complaints (sr) | 6 |
| Neighbor complaints (fr) | 3 |
| Farm thefts (sr) | 7 |
| Farm thefts (fr) | 5 |
| Vandalism (sr) | 3 |
| Vandalism (fr) | 3 |
| Trespassing (sr) | 2 |
| Trespassing (fr) | 3 |
| Lack of communication and awareness (sr) | 3 |
| Lack of communication and awareness (fr) | 3 |
| **Max component points** | **7** |

Appendix 9.20: Macroeconomic Indicators Used to Develop Scenarios

| **US** | | | **Hawaii** | | |
|---|---|---|---|---|---|
| **U.S. Macroeconomic Indicators Affecting Hawaii's Agriculture** | **US Military and Foreign Policy** | **Rest of (U.S.) Private Economy (including energy and capital)** | **Hawaii Population, Demographics, Labor Force, Lifestyle** | **Hawaii Tourism and Development** | **State & Local Government, Policies, Infrastructure** |
| *Distribution/ equality of income*: Widening or narrowing gap between the upper and lower income groups and a concentration of wealth will affect the consumption and expenditure trend. | *Military presence in the Pacific Basin and Asia:* Changing military presence in the Pacific Basin and Asia will impact Hawaii's economy. | *Capital Investment*: Changes in capital investment inflows will affect Hawaii's economy. | *Population Growth*: Changes in population growth in Hawaii will affect employment and consumption. | *Visitors:* Changes in number of visitors to Hawaii will impact the economy. | *Roads, seaports, airports and monorail:* Future investments on transportation infrastructure such as roads, airports, ports and monorail will enhance economic growth. |
| *GDP*: GDP growth rate will impact the State's economy. | *Military expansion*: Military expansion would impact government expenditure and employment opportunities. | *Price of oil:* The price of oil will continue to impact the economy. | *Aging resident population/emigration*: Emigration of young population and increase in the aging population will impact labor availability. | *Air service*: Improved air service will bring about a boom in the tourism industry causing a positive impact on the economy. | *Water delivery system, sewage system:* Better infrastructure facilities such as improved water delivery systems, sewage systems, will enhance economic growth. |
| *Per-capita income*: Changes in the per-capita income will affect tourist dollars spent in Hawaii, resulting in a higher *per-capita income* for Hawaii. | *Ally relationships*: Strategic ally relationships with Japan, South Korea and others will influence trade flow and stabilize national security. | *Renewable energy technology, government policies*: Introduction of new policies encouraging renewable energy supply will enhance economic growth and development. | *Labor Force:* Greater need for skilled labor might increase demand for mainland and foreign labor. | *Sun-and-fun tourism*: Changes in demand for other types of tourism will impact Hawaii's economy. | *Taxes and revenues:* Changes in income, sales, property, corporate taxes, and revenues will impact economic growth. |
| *Interest rates:* Level of Interest rates set by the Federal Reserve will impact banks' lending policy. | | | *Cost of Living & Housing*: The cost of housing will impact the cost of living. | *Cruise lines:* Cruise lines will play a crucial role in the tourism industry. | *Electricity:* Low dependency on electricity due to technological advances will impact the economy. |
| *Value of U.S. dollar*: | *Terrorist attack (I):* A | *Outsourcing:* | *Part-time vs. full-time* | *Aloha spirit:* Change in | *Communication* |

| US | | | Hawaii | | |
|---|---|---|---|---|---|
| Strength of the U.S. dollar versus foreign currencies, such as the yen, will influence Hawaii's economic growth. | terrorist attack on a U.S. military base in Hawaii might lead to an increase in defense spending for Hawaii. | Outsourcing of service business enterprises will affect employment opportunities in Hawaii | *labor*: Changes in part–time labor vs. full-time labor will affect productivity. | aloha spirit will impact the tourism industry in Hawaii. | *infrastructure:* Improvements in communication infrastructure would improve efficiency and impact Hawaii's economic growth. |
| *Federal government fiscal policy*: Expansionary and contractionary fiscal policy may impact the rate of inflation, employment etc. | *Terrorist attack (II):* A terrorist attack would also have negative implications for the tourism industry in Hawaii | | *Social Security*: Increased age limit for social security could impact labor supply and quality. | *Development regulations and costs (price of land, zoning, impact fees):* Changing development regulations and zoning laws may make Hawaii either less or more desirable for developers. | *Overall government spending and debt:* Changes in spending and deficit would impact inflation rate. |
| | | | *Unions:* Strength of the unions will play an important role in the productivity of the labor force. | *Development of high-tech industries (e.g. computer-related, ocean technology, health/medical, and biotechnology):* Development of high-tech industries will impact the economy. | *Native Hawaiian sovereignty:* Passing of the Akaka Bill will have an impact on the economy. |
| | | | | | *Political culture/climate:* Change in political party leadership will impact government policy which in turn will impact the economy. |

Appendix 9.21: Projected Change in Crop Acreages for 10 Studied Irrigation Systems, without Rehabilitation (acres)

| | Most Likely Scenario | | | Optimistic Scenario | | | Pessimistic Scenario | | |
|---|---|---|---|---|---|---|---|---|---|
| **ALL CROPS BUT BIOENERGY** | **2004 - 2005** | **2005 - 2015** | **2015 - 2030** | **2004 - 2005** | **2005 - 2015** | **2015 - 2030** | **2004 - 2005** | **2005 - 2015** | **2015 - 2030** |
| | **acres** | **acres** | **acres** | **acres** | **acres** | **acres** | **acres** | **acres** | **acres** |
| Kekaha | 193 | 2,005 | 3,029 | 377 | 4,007 | 6,855 | -33 | -320 | -92 |
| Kauai Coffee | 83 | 880 | 1,145 | 144 | 1,547 | 2,439 | 0 | 6 | 99 |
| East Kauai | 85 | 901 | 1,169 | 146 | 1,574 | 2,476 | 2 | 28 | 126 |
| Waiahole | 46 | 478 | 778 | 90 | 954 | 1,694 | -3 | -23 | 37 |
| Waimanalo | 33 | 347 | 525 | 64 | 678 | 1,161 | 0 | 2 | 48 |
| Molokai | 63 | 646 | 963 | 127 | 1,339 | 2,276 | -9 | -90 | -99 |
| West Maui | 50 | 528 | 664 | 89 | 955 | 1,485 | -2 | -12 | 3 |
| Upcountry Maui | 62 | 646 | 958 | 117 | 1,248 | 2,113 | -6 | -53 | 30 |
| Waimea | 161 | 1,701 | 2,528 | 282 | 3,041 | 5,148 | -9 | -79 | 402 |
| Lower Hamakua | 446 | 4,627 | 6,758 | 871 | 9,248 | 15,565 | -67 | -698 | -416 |
| **ALL CROPS BUT PASTURE AND BIOENERGY** | | | | | | | | | |
| Kekaha | 36 | 401 | 713 | 46 | 519 | 1,000 | 4 | 46 | 451 |
| Kauai Coffee | 44 | 479 | 566 | 61 | 675 | 975 | 9 | 98 | 235 |
| East Kauai | 46 | 500 | 590 | 63 | 702 | 1,012 | 11 | 120 | 262 |
| Waiahole | 9 | 95 | 226 | 11 | 122 | 297 | 6 | 64 | 167 |
| Waimanalo | 8 | 92 | 157 | 11 | 124 | 230 | 6 | 61 | 134 |
| Molokai | 6 | 63 | 121 | 6 | 71 | 148 | 4 | 44 | 99 |
| West Maui | 27 | 291 | 322 | 40 | 440 | 621 | 4 | 43 | 83 |
| Upcountry Maui | 16 | 172 | 273 | 19 | 217 | 384 | 5 | 55 | 191 |
| Waimea | 72 | 790 | 1,212 | 94 | 1,059 | 1,822 | 12 | 129 | 711 |
| Lower Hamakua | 89 | 980 | 1,494 | 117 | 1,322 | 2,260 | 17 | 136 | 819 |

Appendix 9.22: Delphi Panel Estimated Allocation of 2005-2030 Growth in Crop Acreages by Island

| Crop Group | Kauai | Oahu | Molokai | Maui | Hawaii |
|---|---|---|---|---|---|
| Sugarcane | 23% | 9% | 8% | 49% | 10% |
| Pineapple | 9% | 28% | 11% | 47% | 6% |
| Seed Crops | 26% | 16% | 25% | 18% | 15% |
| Vegetables & Melons | 19% | 17% | 20% | 7% | 37% |
| Fruit & Nut Trees | 28% | 4% | 4% | 16% | 49% |
| Nursery & Flowers | 22% | 14% | 3% | 18% | 43% |
| Pasture | 22% | 7% | 8% | 13% | 50% |